A PRACTICAL INTRODUCTION TO THE STUDY OF BOTANY

A PRACTICAL INTRODUCTION
TO THE
STUDY OF BOTANY

(Specially intended for the use of Indian students).

BY

SIR J. BRETLAND FARMER, M.A., D.Sc., LL.D., F.R.S.
PROFESSOR OF BOTANY IN THE IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY, LONDON
AND FORMERLY FELLOW OF MAGDALEN COLLEGE, OXFORD

AND

HARAPRASAD CHAUDHURI, M.Sc., Ph.D., D.I.C.
READER IN BOTANY IN THE UNIVERSITY OF THE PANJAB, LAHORE

NEW EDITION

LONGMANS, GREEN & CO., LTD.
6 OLD COURT HOUSE STREET, CALCUTTA
53 NICOL ROAD, BOMBAY
167 MOUNT ROAD, MADRAS. S C.
1926

PRINTED IN INDIA
BY GEORGE KENNETH
AT THE DIOCESAN PRESS, MADRAS 1926– C11899

PREFACE

THE present work represents an attempt to enlarge the 'Practical Introduction to the Study of Botany' so as to render it useful to students in India. The new matter has been almost entirely contributed by Dr. Chaudhuri, my own share being mainly limited to the revision of the MS. for the Press.

It is primarily intended to be used as a *practical* guide to the study of plants, but it was thought that the incorporation of certain theoretical considerations, even though presented in the barest outline, might be acceptable as indicating some of the modern trends of botanical science with which students are expected to become acquainted. Such excursions into matters which may be judged by some to lie outside the range of a book like this have been purposely very brief, and it is intended that they should be regarded rather as the mere openings leading to avenues which students may profitably explore under the guidance of their teachers.

J. B. FARMER

CONTENTS

PART I.—GENERAL MORPHOLOGY OF PLANTS.

PART II.—INTERNAL ANATOMY AND MINUTE STRUCTURE OF PLANTS.

PART III.—PHYSIOLOGY OF PLANTS.

PART IV.—CLASSIFICATION AND EXAMPLES OF NATURAL ORDERS OF FLOWERING PLANTS.

PART V.—EXAMPLES OF NATURAL ORDERS OF CRYPTOGAMS.

PART VI.—ECOLOGY, EVOLUTION, HEREDITY.

BOTANY

PART I

GENERAL MORPHOLOGY OF PLANTS

CHAPTER I

GENERAL STRUCTURE OF A PLANT

Material required.—Seedling and young plants of Common Marigold **(Tagetes patula), Amarantus viridis,** Mustard **(Brassica nigra),** Balsam **(Impatiens Balsam),** and Shepherd's Purse **(Capsella Bursa-pastoris).**

CAREFULLY dig up and wash the soil from the roots of young plants and seedlings of Amarantus or Castor Oil plants or better still of all the five specimens and make out the following points in them :—

1. The **Root**; the portion embedded in the soil.

Notice—

(*a*) That it is not green.

(*b*) That it does not bear any green leaves.

(*c*) That it consists of a main, or **Tap-root,** on which more slender roots arise **laterally.** These lateral branches of the root may themselves branch again.

A careful study of the root system (best seen in very young specimens) will disclose the fact that the youngest roots are always nearest to the growing apex of the mother root from which they spring. We express this relation by saying that they arise in **acropetal succession.** This (normal) sequence is less easily discerned in older plants, because growth is not always uniform, and so some of the really younger roots may have become larger than older ones.

2. The **Shoot**; this includes, in our specimens, the portion of the plants which is above the ground.

Observe—

1. That it is green.
2. That it consists of a stem bearing the leaves.

The shoot is made up of a stem, or **Axis**, and those appendages borne laterally upon it which we call **Leaves.**

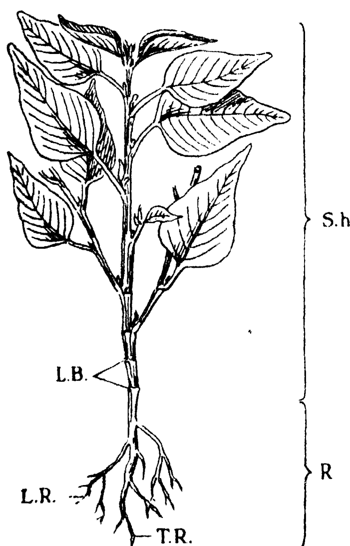


FIG. 1.—*Amarantus viridis.* Sh., shoot; R., root; LB., scars where old leaves have fallen off; T.R., tap root; L.R., lateral roots.

Examine a young seedling, and you will find near the base of the shoot two green leaves, opposite to each other, and differing in form from all the rest of the leaves: these are the seed-leaves, or **Cotyledons.** (These will not be seen in older specimens.)

Above the cotyledons you find the leaves characteristic of the rest of the plant.

Observe—

1. That they are borne singly (not in opposite pairs, like the cotyledons) on the stem. The

transverse plane of the stem where a leaf is borne is called a **Node**, and the interval between two successive nodes is termed an **Internode.**

2. That as you approach the growing end of the shoot the internodes become shorter, and hence that the leaves are more closely crowded together.
3. That they get smaller and smaller as you approach the apex, indicating that they arise in acropetal succession.
4. That at the end of the shoot they become closely packed into a vegetative **Bud.**

Observe the difference in appearance between the upper and lower surfaces of the leaf, and determine what are the characters which effect the difference.

Identify the **Axil** of the leaf, and also the **Median Plane** of the leaf.

Observe that a small lateral vegetative bud is situated in the axil of each leaf in the median plane. These buds, when they develop, will repeat the character of the shoot on which they arise, and are hence called **Branches. Appendages** do not repeat the structure of the part on which they are borne: thus leaves are appendages, and not branches, of the stem.

The origin of branches in the axils of the leaves is very common, though not universal, in flowering plants.

We have seen that the leaves arise in acropetal succession on the stem, and they are also situated at definite distances from each other.

If you take a Rose plant or the common weed *Euphorbia Helioscopia*, you will find that if you start from any one leaf, that the next one (situated at the next node above) is at a considerable distance farther round the stem, i.e., that the **angle** between the two leaves is rather a large one. And the same will hold good for the second, third, fourth, and so on.

Follow the leaves round the stem up the successive

nodes till you come to a leaf standing vertically above the one from which you started. In this case you will find it to be the **sixth,** and if you pass on to the seventh, you will find it falls vertically above the second, and so on. Thus, after you have passed **five** leaves, you come to leaves which merely repeat the arrangement. Such a set (here five) of leaves forms what is known as a **cycle**; and each successive cycle may (and usually does) repeat the characters of its predecessors.

If now you join the bases of consecutive leaves by a thread of cotton or by an ink line, you will find that you have traced a spiral line round the stem, and hence the leaf-arrangement, or **phyllotaxis,** is here said to be **spiral.**

From the data you have now collected you can determine what is the **angle** between two consecutive leaves.

If you had found that all five leaves were passed in going round the stem **once,** of course the interval between any two would have been $\frac{1}{5}$ of a circle of 360°, i.e. 72°. But you will notice that you have to pass **twice** round the stem before the cycle is completed, so that the real difference is doubled, and hence each leaf is separated from its neighbour by $\frac{2}{5}$ of 360°, i.e. 144°. This constitutes the angle of divergence for the leaves of Rose and **Euphorbia Helioscopia.**

You will find it is the same for very many other plants, though by no means for all. And in this case, as in others, we represent the leaf-arrangement, or **phyllotaxis,** as it is called, by the fraction (here $\frac{2}{5}$) of the circumference intervening between two consecutive leaves.

[The reason why the leaves are separated in this way lies in the fact that each leaf requires direct **light** to enable it to perform its function properly; and thus, as they diverge from one another in the way you have seen, each leaf is prevented from unduly shading its neighbours.]

Observe the leaves more closely, noticing especially—

1. Their **Form,**—rather oval, but tapering gradually to the base, and more quickly to the apex.

2. The Leaf-stalk, or **Petiole,** which passes gradually into the Blade, or **Lamina.** Observe that the lamina extends as a wing along both sides of the petiole. Compare this with what you find in the Mignonette and Wallflower.
3. The 'Veins,' or **Vascular Bundles** of the leaf. These branch out from the midrib, and are best seen on the under surface. The veins form a network in the green part of the leaf: hold the leaf up against the light in order to see this. On account of the netlike tracery, the **venation** (arrangement of the veins) is said to be **reticulate.** The character of the venation should **always** be attended to when studying the leaf. It is well seen in 'skeleton leaves,' in which the green softer parts have been removed and the more resistent parts of the 'veins' alone remain.
4. The Margin of the leaf. It is unbroken, or at most faintly toothed. [N.B.—In some sorts of Marigolds the leaf-margin is very deeply lobed.]
5. The Hairs on the leaf, and their special distribution over certain parts of it. Notice that below the node at which the leaf is inserted the stem is ribbed, one of the ribs corresponding to the midrib of the leaf, whilst two lateral ones continue the direction of the winged margins of the petiole.

Next procure a number of plants of the common Shepherd's Purse **(Capsella bursa-pastoris).** Observe the rosette of **Radical** leaves, and compare those of the different specimens. They will probably be found to differ a good deal from each other. Some plants will have all or most of their leaves **entire** and of an **obovate** or **spathulate** form, whilst others may be more **lanceolate,** and perhaps deeply pinnatifid. [A collection of the plants

should be made from different localities, and they should be carefully compared, their differences being analyzed and tabulated as fully as possible.]

Note the **Cauline** leaves, which are borne on the upright stem. These differ more or less in form from the radical leaves, and they are sometimes destitute of a petiole, in which case they are said to be **sessile** on the stem.

Thus this plant affords an example of a shoot exhibiting different characters on the same individual (radical and cauline leaves); and also it is a striking case of a variable species—that is to say, that different individual plants differ in the form of parts which otherwise correspond to each other.

CHAPTER II

GENERAL STRUCTURE OF THE SHOOTS

Material required.—Shoots of apple, Golden Rain (**Cassia fistula**), Siris (**Albizzia Lebbek**), Nim (**Melia Azadiracta**), Banyan (**Ficus bengalensis**), Salvia, Rose and Grass.

EXAMINE a leafy shoot of the Apple. Notice that there are two kinds of branches—

(1) The elongating shoots of the main branches, which may attain to a length of a couple of feet or more ;

(2) Short branches, with reduced internodes, and consequently crowded leaves. These are the '**Fruiting Spurs.**' They are connected with the elongated barren twigs by transitional forms.

On one of the long barren branches observe—

1. The woody axis or stem, covered with a dark-coloured **Bark**.
2. Light-brown spots, raised rather like small pustules on the surface of the bark. These are the **Lenticels**, or breathing pores, through which the air can obtain access to the inner parts of the stem.

Make out the phyllotaxis of the leaves and the presence of axillary buds. Determine the form and venation of the leaves, and the character of their margins. These are all variable in the different sorts of Apples, and often even on the same tree. Carefully observe the two outgrowths at the base of each leaf. These are the two **Stipules.** They are often missing from the older leaves of a twig, through having fallen off.

Stipules are found in a large number of plants. Sometimes they are green, leaf-like, and **persistent**; often they are small, and in a large number of plants they fall off very soon after the leaf unfolds (**caducous**).

Look at a Golden Rain tree. At first sight what you may consider to be a branch is really a leaf for it bears a bud or a branch in its axil; and what you think are leaves, are really leaflets for there are no buds in their axils. Note carefully—

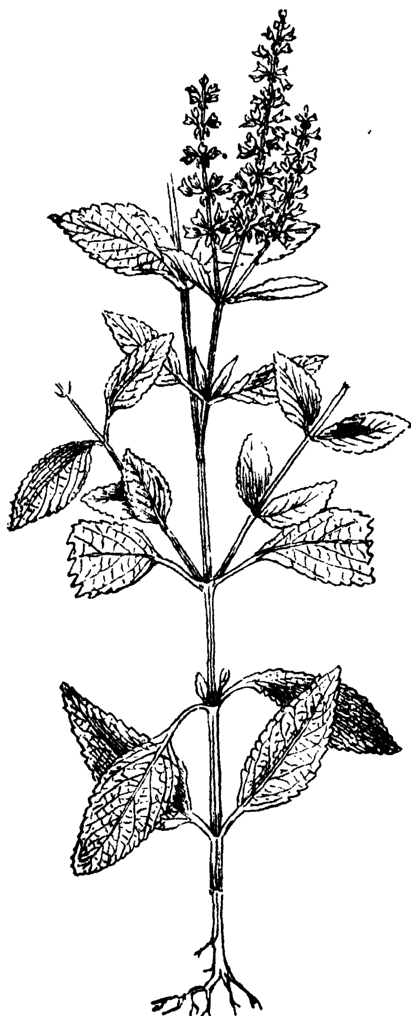


Fig. 2.—The Common Sage.

1. The minute stipules in the branch-like leaves. These fall off leaving scars.
2. That the leaflets **(pinnae)** are arranged along the midrib. Leaves branched in this manner are termed **Pinnate** leaves. Leaflets are equal in number. **(Paripinnate.)**

In Nim note the presence of an odd terminal leaflet **(Imparipinnate)**. Note in Siris, the leaves are alternate, stipulate, compound and the leaflets

unlike those of the Golden Rain tree are themselves divided **(compound bi-pinnate).** In other plants, the leaflets may be divided more than once.

Next take a Salvia plant. Note—

1. That it is an erect herb and the stems and branches are square in cross section (i.e. if you cut them across and look at the cut ends).
2. That the leaves are arranged very differently from those on the plants we have hitherto studied. They occur in pairs, the leaves of a pair being opposite to each other. This is called a **whorled phyllotaxis.** Some other plants have several leaves in a whorl instead of only two, as in **Nerium odorum.**
3. That the whorls alternate with each other; that is, the leaves of one whorl fall over the inter-spaces between the leaves of the whorl below (or above) them. This is almost an invariable arrangement in plants with whorled phyllotaxis, and the whorls are said to be **decussate,** or we may say of this plant that the leaves are **opposite and decussate.**
4. That no stipules are present.

In a twig of the Banyan tree, observe—

1. Grey pubescent (hairy) young shoots and the terminal bud.
2. Leaves arranged alternately; hairy when young, later becoming **glabrous** (smooth). Leaves simple stipulate. Here the stipules are scaly and **caducous**, i.e. falling away very early. The scaly stipules here and as well as in Peepul **(Ficus**

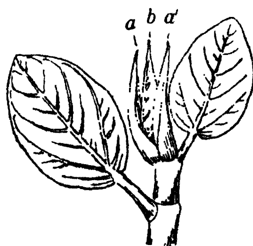


FIG. 3.—Terminal bud of Banyan. *a*, *a*1, stipules; *b*, leaf, unfolding.

religiosa) and Jack fruit tree **(Artocarpus integrifolia)** are protective in function.

3. That the scaly stipule of each leaf protects the next leaf above. This may be seen by dissecting the bud carefully.

The buds that are found in the axils of the leaves are called **axillary,** and when more than one bud are present, **accessory,** as in **Acacia arabica.** Sometimes buds may be seen coming out of the notches of leaves as in Bryophyllum, when they are called **adventitious** buds.

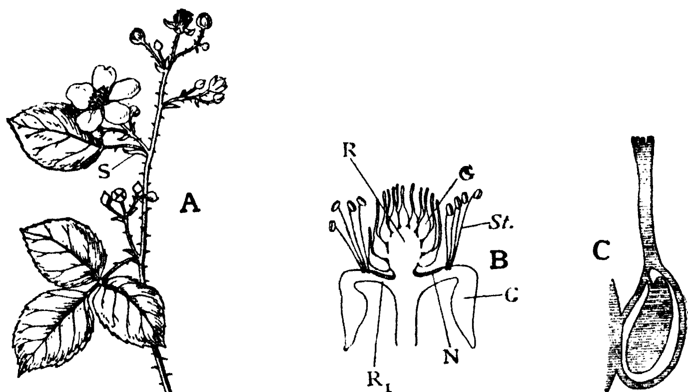


FIG. 4.—Bramble (*Rubus fruticosus*). **A**. Flowering branch: S, stipules. **B**. Flower after petals have fallen: R, receptacle; R_1, expanded part of receptacle ('calyx tube'); N, nectary; C, calyx; *St*, stamens; G, gynæcium. **C**. Carpel containing pendulous anatropous ovule.

Next examine the shoot of the Rose and the Bramble, or Blackberry.

Observe that the stem is provided with **Prickles.** Note their irregular distribution, and that they can be detached from the stem without tearing the inner tissues.

Observe the **Branching** of the leaf; the arrangement of the leaflets; the presence of **Stipules.** The latter appear to spring from the petiole at some distance from its base. They are therefore often spoken of as adhering, or **adnate** stipules. But in reality the leaf base is more highly developed in these than it is in most plants, and passes

gradually into the petiole just at the point where the stipules diverge.

Next take a grass. Any grass is good for our purpose.

Observe that there is no tap-root—even the seedling does not possess one; but there is a mass of '**fibrous**' roots branching out at the base of the stem.

Examine this stem. It is almost the same thickness throughout. It is differentiated into nodes (the knots) and internodes. Branches, usually prostrate, arise in the leaf-axils of the lower nodes.

Carefully examine the leaves. They arise singly at a node, and have a very broad base of insertion; in fact, they surround the stem. Distinguish the **sheathing** portion and the **lamina,** and observe the ragged **Ligule** at the junction of the sheath and lamina.

Note the venation of the leaf. It differs from that of all the plants as yet studied, in that the 'veins,' for the most part, run **parallel** to each other, with but little connection or fusion **(anastomosis)** with one another.

This **parallel venation** is one of the most important characters of the great group of Monocotyledons—a group including all Grasses, Sedges, Palms, Lilies, Orchids, and a few more orders of plants, whilst the **reticulate venation** is characteristic of Dicotyledons; the plants which we studied before the Grass all had reticulate venation, and were Dicotyledons.

We can now summarize what we have learned from a study of the foregoing plants.

An ordinary flowering plant consists of an underground **Root,** which branches freely, and, in many Dicotyledons, is the direct downward prolongation of the stem (tap-root). Roots may also be formed **adventitiously** on the stem in some plants. The roots possess no appendages, but only branches.

The **Shoot** consists of axis (stem) and appendages (leaves). It may either be exclusively above the ground,

or may also be partly situated in the soil, in which it may creep and branch. The branches most often spring from the leaf-axils. The leaves themselves, as we have seen, exhibit great variety of form: they may be simple, or may be more or less deeply cut, or they may **branch.** The branching of the leaf may be either pinnate or palmate.

We have further seen that the leaves may be arranged on the stem either spirally or in whorls, but that in either case the final position actually taken up by the leaf **as a whole,** is dependent on the conditions of illumination. The actual position of its **insertion on the stem** with regard to other leaves, however, is very seldom affected. This remains unchanged, though it may be difficult to find out what it really is.

We have seen that the leaves of many plants bear stipules, and that, in the woody examples we have studied, some leaves become **modified** to form bud-scales to shelter the tender young organs during the winter seasons.

Finally, we have seen that leaves and stems may bear hairs or prickles, irregularly placed structures which are usually outgrowths of the superficial layers of the plant; they are often termed **Emergences.**

CHAPTER III

MODIFICATION OF STEMS

Material required.—Plants of Doob grass **(Cynodon dactylon)**, Mint **(Mentha viridis)**, Oxalis, Marsilia, Ginger, Turmeric and Canna.

THE stems of many plants are creeping, and they are often rooted at the nodes. When the internodes decay, the shoots at the nodes may form new plants.

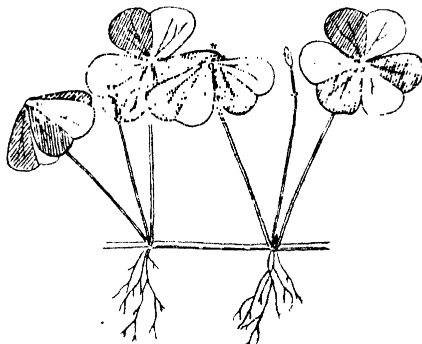


FIG. 5.—*Oxalis corniculata*. Creeping stem, with adventitious roots springing from the nodes.

As an example of a plant with creeping stem we may select **Oxalis corniculata** which is found in nearly every part of the country. Observe—

1. The stem creeps and that adventitious roots arise at the nodes.
2. Branches ascending, hairy and stem much branched.
3. That the leaves are long stalked, compound trifoliate (i.e. three leaflets), alternate.
4. That the petioles are twisted so as to enable each leaf to rise up from the ground.

5. The stipules united at the stalk.
6. The position of the leaf-blade is such as to catch the greatest amount of light.
7. That from some of the leaf axils lateral branches arise which repeat the character of the parent shoot.

Next look for a Marsilia plant and observe—

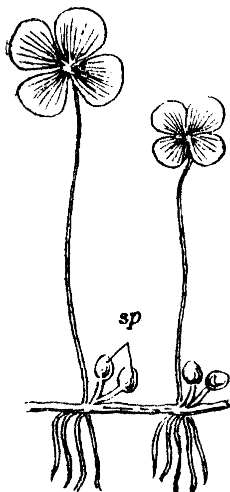


FIG. 6.—Marsilia quadrifoliata, *sp.*, sporocarps.

1. The prostrate stem. Plants growing in water or in moist places.
2. Leaves long stalked with four wedge-shaped leaflets given off laterally.

Now examine a prostrate stem of Cynodon and note that roots, scale leaves and branches are given off from the nodes of the horizontally running stem. Only these branches grow erect. Such creeping stems are called **Runners** or **Stolons** and their erect shoots **Offsets.**

Stolon.—Take a plant of the common Potentilla, carefully avoiding breaking the prostrate stem.

Make out, starting from an established, well-developed plant, that one or more of the prostrate **Stolons** or **Runners** arise in the axils of the leaves.

Follow one of the stolons, and observe—

1. That it forms a long internode, and that at the first node it becomes a leafy shoot.
2. That the stolon appears to run on. But carefully examine the arrangement of leaves at the node, and observe on the under side of the stolon a reduced leaf. This really belongs to the leafy bud, and from its axil a new stolon-branch originates, which continues the direction of growth of its predecessor.

3. That other new stolons may be started from the axils of the other leaves of the young plantlet.

Thus the apparently continuous stolon is really made up of a number of branches, which have together formed an apparently simple axis, and the stolon is thus a **sympodium.** The true state of affairs can be decisively established by examining the positions of the leaves. Thus the long stolons are really **sympodia.** Compare with the Potentilla a Strawberry plant bearing runners.

Observe—

1. That the stolons are branches arising in the axils of leaves.
2. That the stolons are sympodia.
3. That they possess one barren node with reduced leaves.
4. That at the second node any one stolon-axis ends in a leafy shoot.
5. That the direction of growth of the stolon is continued by a lateral branch in the axils of one of these leaves.

Next dig up a patch of Mint and observe—

1. The underground stem bearing reduced scale leaves.
2. The branches from the axils of the scale leaves.
3. That these branches have a tuft of adventitious roots at their bases.
4. That they grow erect and produce green leaves. These stem structures are known as **Suckers.** The underground stems take different forms in different plants. When these elongate horizontally, growing at one end and dying at the other, they are known as **Rhizomes** or **Root-Stocks.** Examples in Ginger **(Zingiber officinale)**, Turmeric **(Curcuma longa)**, **Canna indica,** Lotus, Plantain, etc.

CHAPTER IV

MODIFICATION OF STEMS (*Continued*)

Material required.—Plants of **Panicum repens, Amorphophallus campanulata** (Arum), **Colocasia antiquorum, Helianthus tuberosus** (Jerusalem Artichoke), Potato, Crocus, Passion-flower, Asparagus, Onion, Jawan, Sloe, Duranta, Dolichos, Opuntia, Ruscus, etc.

MANY rhizomes swell up, either locally or entirely, and in this way become adapted to act as storehouses of food.

Examine the rhizomes of the grass **Panicum repens.** Observe that the rhizome is swollen like a row of beads. Observe the position of the leaves, this will indicate that the swollen portions of the stem are the consecutive internodes only.

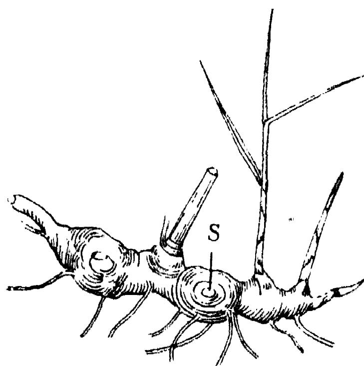


FIG. 7.—Rhizome of Panicum. S., scar.

Carefully make out the mode of branching, and especially the production of the leafy stems which appear above ground.

Other rhizomes swell up more or less entirely. Examine a plant of Jerusalem Artichoke (**Helianthus tuberosus**). Note the underground short rhizomes given off in the axils of the scale-leaves on the lower parts (underground) of the stem of the plant. Observe that these are thickened in both nodes and internodes, and that the nodes are clearly marked both by scale-leaves and the buds in the axils of these scales.

Compare the Potato with the Artichoke. Dig up a Potato plant on which the young potatoes are about half

grown, and observe that they form as swellings at the ends of thin underground stems. Note the small scale-leaves, with the buds ('eyes') in their axils. These thickened, more or less rounded underground stems are known as **Tubers.**



FIG. 8.—A potato plant with tubers. *e*, 'eyes.'

Corms.—Dig up some Crocuses when they are in flower, and observe.—

1. The short swollen underground stem, or **Corm.** Cut it down the middle, and note that it is solid. Note that roots arise from its lower surface, and that below it are the shrunken remains of the corm of the previous season.
2. The brown membranous withered scale leaf-bases. Peel these off, and note the circular scar they leave. The leaves of this plant encircle the stem at the nodes. Note also the small buds present in their axils. Several of these buds may occur in the axil of one leaf.

3. That higher up we find the circular scar of old foliage leaf-bases.
4. Situated above the old corm, the base of the shoot which terminates in a flower.
5. The base of this shoot surrounded by several (3-5) scale-leaves.
6. Above these come the foliage-leaves, variable in number. Peel off the scale-leaves and the foliage-leaves, and observe that both of them encircle the entire stem at their insertions.
7. Close beneath the flowering shaft, the small bud which will produce a flower in a subsequent year.

Dig up a Crocus from which the flower has quite faded. Observe—

1. That the base of the stem, where the young outer scale-leaves and the foliage-leaves are inserted, is swelling to form the new corm for the following year.
2. That this corm is growing at the expense of the one of the current year, which is rapidly shrinking in size.
3. One or more large thick fleshy roots which spring from the base of the new corm.
4. Other thin roots, rising side by side with these fleshy roots, which are best seen in Crocuses growing in sandy soil.

Dig some more plants up after the lapse of a few weeks. The thick roots will be found to be no longer noticeable. They function as **contractile organs**, to drag down the new corm to the level of the old one, and when this is effected, they become shrivelled and indistinguishable, except by careful scrutiny, from the rest of the roots.

A careful comparison of the Crocus with the foregoing plants will lead to the conclusion that it really is a short sympodium, each separate corm with its terminal flower representing one axis.

In Freesia, the young corms are not formed at the apex, but on the sides, so that the remnants of the old corm are not seen at the base.

Bulb.—Examine the underground stem of Onion. Note that it consists of a small disc which is enveloped by fleshy leaves. Buds are present in the axils of the young leaves. The leaves here are called **scale-leaves** and the outer scale leaves are membranous. Such a structure is known as a **Bulb.** On the under-surface of the disc, note that numerous roots are borne.

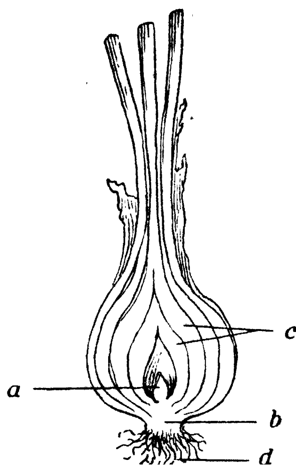


FIG. 9.—Section of Onion. *a*, growing point; *b*, disc; *c*, scale leaves; *d*, roots.

Stem-Spines or **Thorns** may be studied in Jawan (**Alhagi maurorum**), Sloe (**Prunus spinosa**), or in hedge Duranta. Examine a branch of Jawan and note that—

1. The spines are borne in the axils of the leaves.
2. They bear flowers. This shows their true nature. In Duranta, a commonly cultivated plant, leaf-bearing spines are found and hence these are really modified axillary shoots.

Tendrils.—Examine a shoot from the Passion Flower plant. Observe the stipulate leaves, bearing in their axils a tendril. In this case, therefore, the tendril represents a branch.

It is a slender delicate coiled structure.

Observe that **accessory buds,** which may develop to leafy shoots, are also borne in addition to the tendrils, in the leaf-axils.

Carefully study the way in which the tendril grasps a support, and the manner in which it is spirally coiled

(after it has become attached) in the part between the plant and its support. Observe the reversal of the spiral.

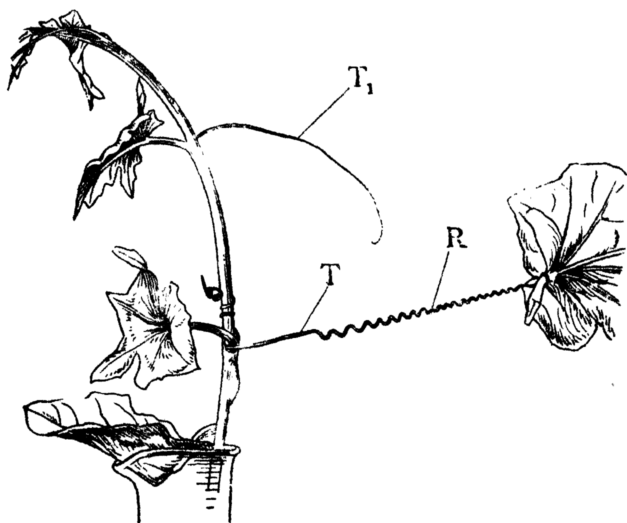


Fig. 10.—White Bryony (*Bryonia dioica*) with tendril (T) holding on to a support; R, the point of reversal of the spiral; T_1, tendril not yet grasping any support.

Fix a bit of string to two sticks, as if it were a tendril, and then take the middle of it between the finger and thumb and twist it. Observe that it forms the same sort of reversed spiral as does the tendril.

The gourds and cucumbers may be advantageously compared with the above in respect of their tendrils.

Twiners and Lianes.—Certain plants like **Dolichos Lablab** and **Clitoria Ternatea** have to twine themselves round a support, because of their weak stems. Such plants are called **Twiners.** When the twiners have thick and massive stems, they are known as **Lianes.**

Cladodes.—Certain plants, instead of producing rounded stems only, have some of their lateral axes flattened as to resemble leaves. These flattened branches are **Cladodes.**

Examine a shoot of Butcher's Broom **(Ruscus aculeatus)**, selecting for the purpose a young bright-green shoot.

Observe—

1. The main axis, which branches several times.
2. On the branches are finally borne thick, ovate, sharply pointed structures. These are seen to arise in the **axils** of minute scale-leaves. They are cladodes.
3. The position of the cladodes : they are twisted so as to face obliquely, or edgewise, towards the sky.
4. On the apparent midrib, about a third up the length of the cladode, observe a swollen bud (best seen in older specimens) in the axil of a scale-leaf. This will develop into a flower.

Thus the cladode of **Ruscus** not only arises in the axil

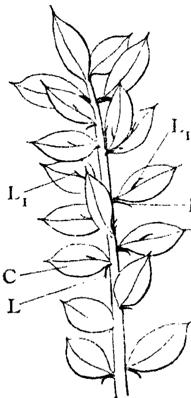


FIG. 11.—Butcher's Broom (*Ruscus aculeatus*). L, scale-leaf, in the axil of which is borne the cladode (or *phylloclade*) ; C, these cladodes also bear scale-leaves (L_1) on their upper surfaces.

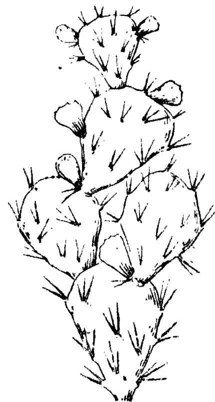


FIG. 12.—Prickly Pear (*Opuntia* Dillenii).

of a (scale-) leaf, but it also bears on its upper face a leaf and axillary bud.

Examine a shoot of Asparagus, such as is used for cooking. Observe the well-marked scale-leaves bearing branches in their axils. Later on, when these branches begin to unfold, observe that they also bear little scale-leaves, and that in the axils of the latter, tufts of green needle-like structures are borne. Careful examination will show that each of these clusters of green needles consists of an aggregation of stems, each needle representing, not a leaf, but a short stem.

Thus the Asparagus, like the Butcher's Broom, does not bear any green foliage-leaves, the function of foliage-leaves being undertaken by the cladodes (branches) arising from the axils of the real leaves, which are reduced to mere scales.

Other examples are Prickly Pear **(Opuntia Dillenii)** **Cocoloba platyclada,** species of Euphorbia, etc.

CHAPTER V

LEAVES

Material required.—Leafy shoots of various kinds (see in the text).

Forms of Leaves.—We have already learned to recognize some of the forms which leaves assume. We will now pay more especial attention to the various shapes which these organs present.

It is of little use doing this unless we try to get an idea, at the same time, of the gradations from one extreme to the other—from the circle to the line—which we can trace; and, further more, we shall lose the most valuable part of the study of leaf-form unless we, at the same time, study the variations which the leaves of the same plant exhibit.

Also it is essential to constantly bear in mind that the primary functions of leaves can only be fulfilled if they are properly exposed to the light. The form assumed by the leaf of any one shoot will betray a distinct connection with (*a*) the character of the stem which bears them, (*b*) their own distance apart from each other.

But besides this, there is the important fact to be remembered, namely, that every present plant has a very long ancestry, and that the structure which it, or any part of it, possesses to-day is the outcome primarily of an **inherited structure,** albeit that this structure is capable of variation, within certain limits, to suit contemporary needs.

In spite of the great multiplicity of leaf-forms, we find they can be fairly well divided into two great classes—the **Branched** and the **Unbranched,** respectively.

I. **The Unbranched Leaves.**—These may exhibit almost every imaginable variety of outline, though some are far more common than others.

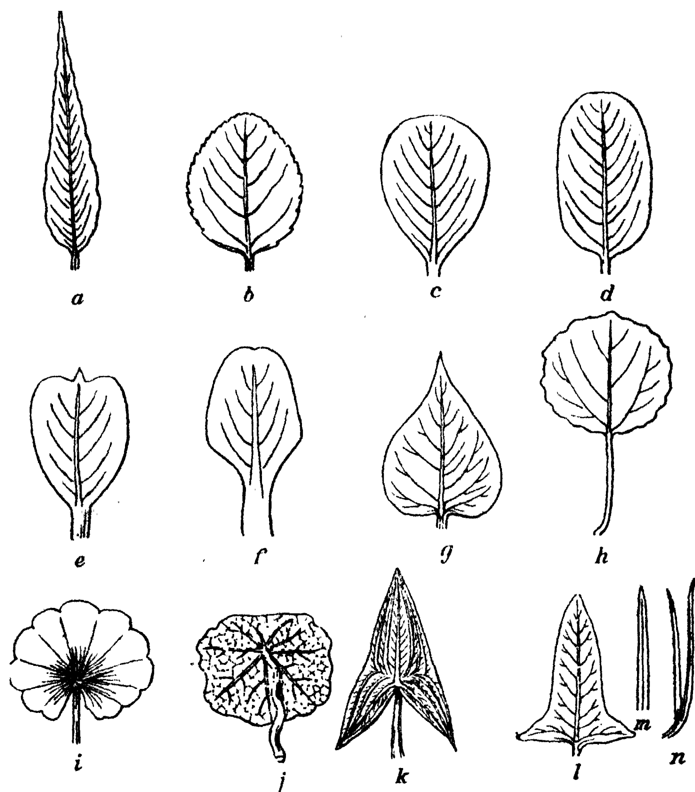


Fig. 13.—Shapes of leaves. *a*, lanceolate ; *b*, ovate ; *c*, obovate ; *d*, oblong or elliptical ; *e*, cuneate ; *f*, spathulate ; *g*, cordate ; *h*, orbicular ; *i*, reniform ; *j*, peltate ; *k*, sagitate ; *l*, hastate ; *m*, linear ; *n*, acicular.

1. The **Lanceolate** type, i.e., lance-shaped ; broad at the middle or a little below and tapers towards the apex, as in Nerium, Polygonum, Bamboo, etc.
2. The **Ovate** type, i.e., egg-shaped ; broad and rounded at the base and tapering to a point at

the apex, as in **Hibiscus Rosa-sinensis** or **Solanum nigrum.** When the arrangement is reversed, i.e. broad and rounded at the apex and tapering towards the base, the term **Obovate** is used as in **Terminalia Catappa, Cassia obovata,** etc.

3. When as in Banyan and Guava leaves, the margins are almost straight and the blade uniformly broad, the term **Oblong** or **Elliptic** is used.
4. The **Cuneate** or wedge shaped type leaves are seen in **Pistia Stratiotes,** Box.
5. The **Spathulate** or spatula-shaped leaves are seen in **Ajuga reptans, Drosera Burmanii.**
6. When the blade is hollowed at the base and pointed at the apex, it is **Cordate** or heart-shaped, as in Aristolochia, **Piper Betel.**
7. The **Orbicular** or round-shaped leaves are found in **Malva rotundifolia,** Nymphaea.
8. When the blade is hollowed out at the base but rounded at the apex it is called **Reniform** or kidney-shaped, e.g., **Hydrocotyle asiatica, Centella asiatica.**
9. When in orbicular or reniform leaves, the petiole is attached to the middle of the lower surface of the blade, it is termed **Peltate** or shield shaped, e.g. Tropæolum.
10. The **Sagittate** or leaves shaped like arrow-heads are seen in **Sagittaria sagittata,** Common Arum, etc. When the basal lobes of sagittate leaves are straight and at right angles to the blade, it is termed **Hastate,** e.g., **Ipomoea repens.**

Beginning again at the lanceolate type, we find another set of plants, the leaves of which are narrower than this type.

11. **Linear** or long leaves as in most grasses.
12. **Acicular** or needle-shaped as in Pine.

Many leaves which can readily be classified under one of the foregoing forms, have their margins more or

less indented. This need not affect the character of the general outline. The leaf margin is termed **Entire** when it is even, i.e. without any indentations. **Repand,** if it is wavy as in **Polyalthia longifolia. Dentate,** if the margin is prominently cut into teeth and pointed as in **Nymphaea rubra. Crenate,** if slightly indented and the teeth are rounded as in **Bryophyllum calycinum, Centella asiatica.** If the teeth are pointed towards the apex as in **Hibiscus Rosa-sinensis,** the term **Serrate** is used.

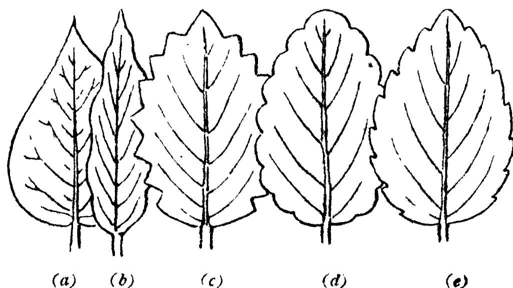


FIG. 14.—Margins of leaves.
(*a*) Entire, (*b*) Repand, (*c*) Dentate, (*d*) Crenate, (*e*) Serrate.

Some leaves have their apex rounded- **Obtuse,** or pointed- **Acute** When the apex of the leaf tapers to a point gradually, it is termed **Accuminate** or **Caudate.** If the apex is cut straight- **Truncate**; if notched- **Retuse**; with a deep notch- **Emarginate.** If a sharp point project from an obtuse apex- **Mucronate,** and when the acute apex is spiny, the term **Cuspidate** is used.

Some leaves may possess a blade but no petiole, and then they belong to the—

13. **Sessile** type. Many cauline leaves belong to this group. A special case of a sessile leaf is found in the—
14. **Decurrent** type, e.g., **Verbascum Thapsus,** or the common Thistle, in both of which the leaf margin is continued (as it were) in the form of a wing on the stem. Again, sessile leaves may have a very broad insertion on the stem,

and when this happens in the case of opposite leaves, it may happen that the two leaves appear to be grown together at their base, forming the—

15. **Connate** form, well seen in Canscora and in the Teazle. Sometimes the broad insertion of the leaf extends quite round the stem in the case of spirally arranged leaves, and then the stem appears to go through the leaf. This is the—

Perfoliate type. The terms **Auriculate** and **Amplexicaul** are respectively used when the base of a sessile leaf is prolonged into two ear like lobes which either partially or wholly clasp the stem.

Transitional forms to the branched types are afforded by the **Pinnatifid**, the **Pinnatipartite**, the **Pinnatisect** on the one



Fig. 15.—Castor Oil plant (*Ricinus Communis*).

hand, and the **Palmatifid**, the **Palmatipartite** and the **Palmatisect** on the other; the terms **Fid**, **Partite** and **Sect** indicating slightly lobed to deeply incised leaves. Examples

of the former are Radish, Lactuca, Argemone and Cocoanut, and of the latter, Gossypium, Pawpaw, Castor Oil plant, and Borassus palm.

II. **Branched Leaves.**

1. **Pinnate** type, e.g., Tamarind, Cassia, Sesbania, Rose, Bramble, etc.

Some pinnate leaves are reduced to three leaflets, forming the—

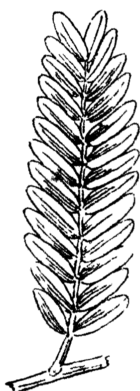


FIG. 16.—Pari-pinnate leaf of Tamarind (*Tamarindus indica*)

(*a*) **Ternate** or **Trifoliate** form, e.g., **Aegel Marmelos**, Bramble, Strawberry.

The pinnae of some pinnate leaves may themselves again be pinnate, forming, (*b*) **Bi** or **Tri-pinnate** forms. Examples of Bi-pinnate in **Albizzia lebek, Acacia arabica, Caesalpinia pulcherima, Poinciana regia.** Examples of tri-pinnate in **Moringa pterygosperma, Melia Azadirachta.**

2. **Palmate** type, e.g., **Bombax malabaricum, Cleome viscosa, Gynandropsis pentaphylla.** In palmately branched leaves, the petiole bears at the apex, a number of leaflets, presenting the appearance of an outstretched hand.

If you now cut transverse sections of some of the above leaves, you will find that the midrib and some of the other ribs of the lamina indicate the course of the vascular bundles. From these ribs numerous branches are given off which constitute the **Venation** of the leaves. The different types of venation you find in the leaves are determined by the type of development of the lamina. Thus in a pinnate leaf, it is pinni-veined ; in a palmate leaf palmi-veined and so on. According to the distribution of the veins and their branches, 'free,' 'parallel' and 'reticulate' types of venation are distinguished. When the veins end free without forming anastomoses at the margin of the leaf, it is said to be **Free.** It is **Parallel**

when the adjacent veins run parallel to each other towards the apex of the leaves or the margin of the blade and then unite by curving inwards as in many grasses. In Peepul, the venation is said to be **Reticulate**, as the veins branch repeatedly at various angles and the branches anastomose.

When in a leaf, there is only one strong midrib, it is **Unicostate.** But when several equally strong veins arise from the junction of the petiole and lamina, as in Tropæolum or Ricinus, it is said to be **Multicostate.**

CHAPTER VI

MODIFICATION OF LEAVES

Bud Protection.—In order to acquire more familiarity with the various ways in which leaves are arranged in the buds, the following plants may be studied: Banyan, Peepul, Mango, Pea, Barringtonia and the Tea plant.

Be careful to distinguish those bud scales which are of stipular nature as in Banyan or Peepul, from those which are true leaves, e.g., Barringtonia, Tea plant. In the buds of the Tea plant, we find a regular gradation from the outermost thin brown scales, through thicker and whiter scales to innermost immature leaves.

Note carefully the way in which the leaf-blade is folded in the bud (**Vernation** or **Perfoliation**).

This can best be made out by cutting cross-sections of the whole bud, mounting them carefully in spirit on a glass slide, without disturbing the arrangement of the parts, and examining with a lens. To do this, take a razor and wet the blade with **spirit**; cut off the top half of the bud, and discard it. Wet the razor again with spirit, and cut thin slices across the bud, being careful to keep the razor **wet the whole time.** When you have about three sections on the blade of the razor, lay it on a glass slide, and with a needle gently push the sections, one after another, on to the slide. This requires a little practice, to avoid disturbing the sections.

When they are safely on the slide, keep them wet with **spirit** whilst you are examining them with a lens. On no account add water to them, as the violent diffusion currents which would arise would almost certainly cause the sections to break up.

The following types of vernations are recognized, viz. :—

1. **Convolute,** when the leaf blade is rolled from one margin to the other as in Musa, Canna.
2. **Involute,** when the two margins roll inwards towards the midrib, the under surface of the leaf being outside as in Banyan, Fig, Nelumbium.
3. **Revolute,** when the margins roll outwards, towards the midrib, the upperside being outermost as in Polygonum, Nerium.
4. **Conduplicate,** when the two halves of the blade are folded along the midrib, in such a way that the upper surface and the edges of the blade meet, as in Anona, Abutilon, Bauhinia.
5. **Plicate,** when the blade is folded upon itself in a pleated manner as in Toddy palm (Borassus).
6. **Circinate,** when coiled like the dog's tail as Ferns, Marsilia.
7. **Crumpled,** when irregularly folded as in Cabbage.

Besides the above the following terms are used to denote the arrangement of the young leaves with respect to one another in the buds, viz., **Valvate,** when the leaves are in whorl with their margins approaching or just touching, but never overlapping. When the margins over-lap, the term **Imbricate** is used. **Equitant,** when a conduplicately folded leaf is wholly or partially enclosed by another leaf similarly folded. Lastly the term **half-equitant** is applied to where two conduplicate leaves enclose each other by half their blades.

Buds are sometimes protected during the early period of their life by the leaf in the axil of which they arise. In some plants (e.g. the Plane-tree) the base of the petiole, gradually forms a hollow conical receptacle in which the young bud lies till the leaf falls off in autumn.

Leaves as Storehouses for Food.—It often happens that the whole or a part of a leaf may become swollen or

otherwise modified to store up food material for the future use of the plant. For this purpose, either—

1. The entire leaf may be modified, or—
2. Part of the leaf (the lower portion) only swells up, whilst the upper part functions as a foliage-leaf.

Examples are found in Freesia, Garlic, Onion, Tube Rose, etc. In Freesia observe—

1. Underground is the swollen bulb, from the base of which spring a few roots.
2. From the middle of the bulb the flowering stem, bearing also whorls of green leaves, arises.
3. Roots (adventitious) spring from the lower part of this stem.

Pull the bulb-scales off, beginning at the base of the bulb, and observe—

1. That they are modified **leaves,** fleshy, and full of reserve food material.
2. That they are inserted on a very short axis.
3. That the outer ones are becoming depleted of their contents.

Carefully make out the position of the flowering stem on the bulb, and observe the scars of past-flowering stems.

Examine a plant of the Onion or the Hyacinth, which is bearing green leaves.

Observe—

1. The shrivelled remains of the dead older leaves.
2. That these completely enwrap the stem.
3. That the bases of the foliage-leaves also enfold the stem.

Study the manner in which the young leaves emerge from the outer enveloping leaves.

Cut the bulbs both across and down the middle, and study the characters and relations of the various parts. Note the position of the flowering stem (if present).

These bulbs, in which the scales completely ensheathe

the stem, are termed **Tunicated** bulbs and when the scales occupy only a small part of the circumference of the stem, the bulbs are known as **Scaly** bulbs.

Insectivorous Plants.—Occasionally leaves are modified as insect traps. The insects are caught and digested by the leaf very much in the same way as we digest the food which we eat. Some plants possess wonderful leaves for this purpose. Thus the leaf of **Nepenthes**, a 'pitcher plant' common in the wet districts of Eastern Bengal, forms a box with a lid over it. The lid remains partly open, and the insects which clamber over the edge of the pitcher slip over the treacherous edge and are drowned in the water which is always present in these structures. The water of the pitchers contain substances which cause the nutritive parts of the insect's body to dissolve, and then the plant is able to absorb the food thus supplied to it. Another pitcher plant, common in the North American swamps, is known as **Sarracenia**.

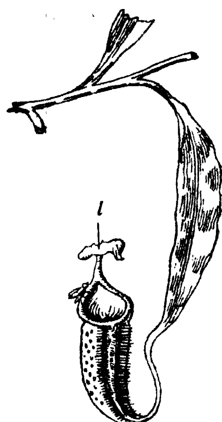


FIG. 17.—Pitcher of *Nepenthes.*

Other insectivorous plants are—

Drosera (Sundew).—On wet heaths we frequently meet with a pretty little plant with leaves spreading out like a rosette, and on the upper surface of each leaf rather long, club-shaped hairs are borne. Each of these bears at its swollen end a glistening drop of a sticky substance, and the beautiful appearance thus produced has caused the plant to be known as Sundew.

When a fly or other small animal settles on a leaf, it is held by the sticky secretion, and soon the other hairs, or tentacles as we may call them, bend over, and so the prey is held faster and faster, and finally smothered. The whole leaf also slowly bends together

over the body of the insect. The tentacles secrete a digestive juice which dissolves the insect's soft parts, and they are then absorbed by the plant.

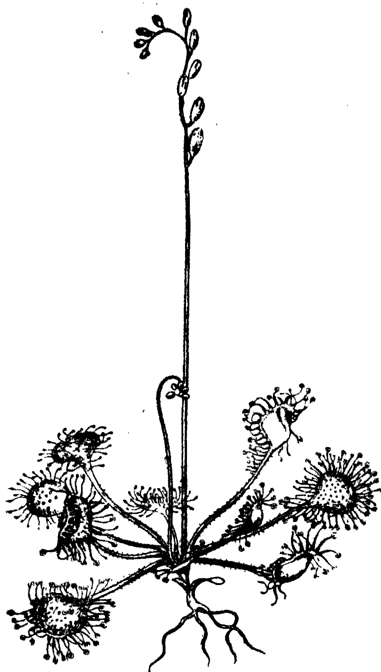


FIG. 18.—Sundew (*Drosera rotundifolia*).

A very slight touch, e.g. a grain of sand, will cause the tentacles to bend over; but unless the foreign body can be digested, they soon straighten out again, instead of closing more tightly over it. You will find that the leaves will often seize more than they can absorb; and indeed it often happens that, after a full meal, the leaf itself dies. But it has been found that plants which have been fed on animal matter thrive better, and set more seed, than those which have not been nourished in this way.

Take some plants of Sundew and grow them in Bog Moss, in a saucer. Feed some of the leaves with small particles of the 'white' of a hard-boiled egg. The particles may be about as large as a pin's head.

Observe—

1. The curving in of the neighbouring tentacles.
2. The inrolling of the entire leaf-surface.
3. The time taken to digest the particles.

In India, **Drosera Burmanii**, and **Drosera peltata var. lunata** are found. The former is found during the winter months

in the Chota Nagpur districts and the latter in the Khasia Hills of Assam and the Simla Hills of the Panjab.

Pinguicula (the Butterwort).—This is a curious yellowish-green plant, with oval leaves, and it is often met with in peaty districts and on mountain bogs of Europe. It is not so active as the Sundew, and it holds its prey whilst digestion is going on by rolling in the margins of its leaves.

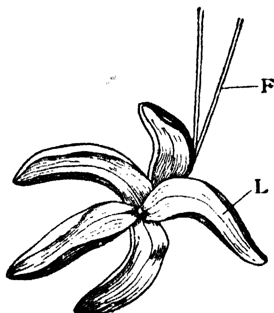


FIG. 19.—Butterwort (*Pinguicula vulgaris*). L, leaf; F, flowerstalk (flower not shown).

Note the glutinous character of the surface.

Examine it with a lens, and make out the **glandular** nature of the upper surface.

Utricularia (the Bladderwort).—This curious water-plant is very common in Bengal, but it also occurs in many other places. It inhabits the water, and its leaves are remarkable, in that parts of them are modified to form hollow bags, or sacs, with a trap-door leading into them.

Observe—

1. Their form.
2. The character of the entrance.
3. The branched hair-like structures on each side of the 'door.'

In examining the bladders of this plant notice how readily the trap-door allows ingress into the bladder, whilst, once inside, escape is impossible. Sometimes the small fry of fish swimming about amongst these plants poke their heads into the bladders ; if its gills get in beyond the edge of the door a fish can seldom pull its head out again, and so it perishes, and contributes to the maintenance of its captor.

Aldrovanda (Malacca Jhangi).—**A. Vesciculosa** is an

insectivorous plant of the salt lakes of Bengal. It is a floating weed. The capturing mechanism of the leaves

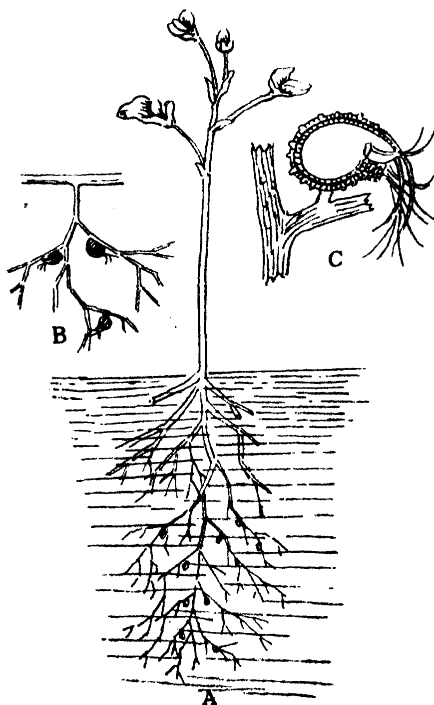


FIG. 20.—The Bladderwort (*Utricularia*). A, complete flowering plant; B, portion of submerged leaves, showing bladders; C, section of a bladder.

of Aldrovanda is like that of the North American species of Venus's Fly-trap (**Dionaea muscipula**).

CHAPTER VII

MODIFICATION OF LEAVES—(Continued)

Phyllodes.—Certain plants, e.g., many Acacias, instead of forming the pinnate leaves characteristic of this group, bear no blades at all on their adult shoots.

Instead of this, the leaf-stalk becomes flattened, whilst the blade portion does not develop.

If possible, examine some **seedling** Acacias, and observe that the first leaves are pinnate. Then leaves arise in which the blade is reduced, whilst the leaf-stalk becomes laterally flattened, and by-and-by the flattened stalks, or **Phyllodes,** only are produced.

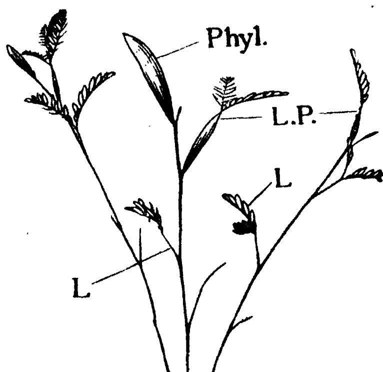


FIG. 21.—Acacia seedlings. Phyl., phyllode; L.P., pinnate leaf with flattened petiole; L., pinnate leaf with rounded petiole.

Some Acacias (e.g. **A. melanoxylon**) produce both leaf-forms throughout the life of the plant, and pruning is usually followed by a production of the pinnate leaves.

Tendrils.—Observe a climbing plant of the Wild Clematis. Study the manner in which the leaf-stalks grasp and twine round a support.

Repeat your observation on **Aristolochia indica,** and if possible on the climbing Tropaeolum.

Examine the Garden Pea **(Pisum sativum).** Observe—

1. The pinnate character of the leaf, with the two large stipules at the base.

2. That the three upper-most pinnæ have commonly become reduced to mere midribs, and that they are able to twine round a support.

3. That those tendrils which have done this grow in thickness, whereas those which have failed to grasp a support remain thin, and often wither away.

4. That the first few leaves of the Pea are not modified at all to form tendrils.

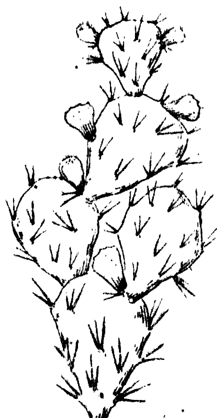


FIG. 22.—*Lathyrus aphaca*. *r*, tendril; *b*, flower; *f* fruit; *n*, stipule.

Examine, if possible, a plant of **Lathyrus aphaca.** Observe that the entire blades of the pinnate leaf is modified to form tendrils, whilst the stipules are enormously developed. The seedling of this plant shows a transition from an unmodified pinnate leaf to this curious adult form.

Spines.—In some plants the leaves may be modified into spines as in Prickly Pear (**Opuntia**). In Citrus and Bougainvillea, the spines are modified leaf buds. In the stems of **Flacourtia cataphracta** big compound spines are present. These stem-spines should not be confounded with the leaf-spines.

On other plants we find that it is only certain leaves that assume a spiny form. The Barberry supplies an example. Note carefully the spiny leaves on the main stems of this plant, and observe that the buds in their axils develop into dwarf shoots bearing foliage-leaves.


FIG. 23.—Prickly Pear.

Observe carefully the transition between the normal leaves and spines, which can frequently be well seen in those shoots of the Barberry which spring directly from the base of the bush.

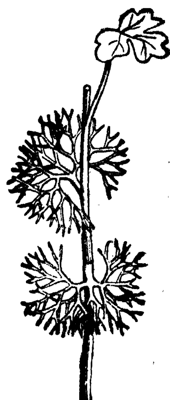


FIG. 24.—Heteromorphic leaves of the Water Crowfoot (*Ranunculus aquatilis*). The floating leaves trilobed, the submerged leaves laciniate.

Heterophyllous Plants.—It sometimes happens that a plant may produce more than one kind of foliage-leaf on the same individual.

In **Ficus heterophylla,** the leaves are variously broad or narrow and unlobed in the same plant. Among land plants, it is also seen in **Euphorbia heterophylla.** Next examine the common water plant **Limnophila heterophylla,** and **Ranunculus aquatilis.** In the former observe—

1. The two uppermost leaves are usually opposite and crenulate.
2. The next below 4–6 nately whorled, pinnate.
3. The lowermost, submerged, multifid, with capillary segments.

In the latter, observe—

1. On the submerged stem the finely cut leaves, the segments of which almost seem to be reduced to veins.
2. The floating leaves, with a variously indented margin.

A very common umbelliferous plant, **Carum Roxburghianum,** may also be examined. Note leaves, ternately cut. The lobes of the lower stem leaves, oblong, linear.

When plants produce more than one form ot leaves in this way, they are said to be Heterophyllous.

The Eucalyptus may be also examined, if opportunity offers, for comparing the leaves on the young plant with the very different ones occurring on the branches of older specimens.

CHAPTER VIII

STIPULES, ROOTS, EMERGENCES

Modifications of Stipules.—Just as leaves may become modified for certain purposes, so also stipules may depart from their ordinary form.

We have already seen them functioning as bud-scales on the one hand, and as green persistent leaf-like structures on the other.

Additional examples which should be examined are Chinese Rose and Tamarind for '**lateral and free stipules.**' The Rose for '**lateral adnate stipules.**' In the Coffee plant, in Ixora and in others where the leaves are opposite, the stipules of the two leaves are joined in pairs to form what looks like one stipule and this forms what is known as an '**interpetiolar stipule.**'

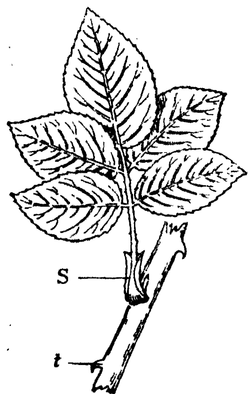


FIG. 25.—A branch of Rose. S, adnate stipules; *t*, prickle.

Examine also the leaves in a young Strawberry plant, and observe carefully the way in which the stipules are arranged on the leaf-base, and the way in which they ensheathe the unfolded younger leaf. This type of stipule leads directly on to the next form.

Examine a leaf of Polygonum and observe that stipules form a complete sheath surrounding the axis. This is known as an '**ochrea.**'

Stipules may be altered to form thorns. In **Zizyphus Jujuba,** the stipules are modified into thorns. Note that at the base of the leaves of the youngest branch, soft stipules are still formed.

Examine the shoots of Tephrosia and observe the spiny stipules, one on either side of each leaf.

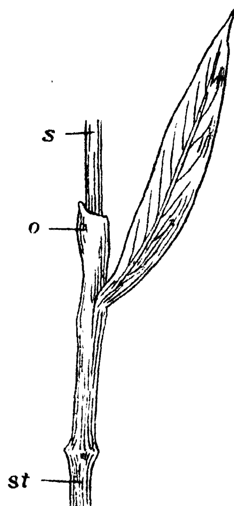


FIG. 26.—A portion of the stem (*s.*—*st.*) of Polygonum with leaf showing Ochrea (*o*).

Modifications of Roots.—Roots are most easily studied in seedling plants. Grow some Kidney Beans or Peas in damp sawdust, and, when the young plants are about an inch or so high above the sawdust, gently remove them, and wash the sawdust carefully from their roots (Fig. 27).

Make out—

1. The main, or **Tap-root.**
2. Its colour.
3. Its form, tapering near the apex. The apex may be examined with a lens, holding it up to the light; and the **Root-cap** may be, though perhaps with difficulty, distinguished.
4. Behind the apex, a velvety region. This character is due to the presence of great numbers of **root hairs.** (They are more easily seen in Wheat seedlings, which have germinated on damp blotting paper, or in damp air over water.)
5. The branching of the root, and that the **Lateral** roots arise in acropetal

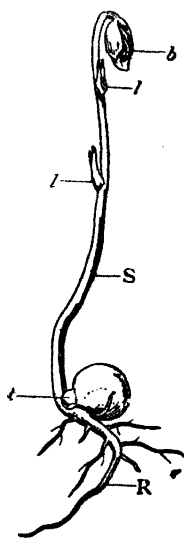


FIG. 27.—Garden Pea. *b*, terminal (vegetative) bud; *l*, *l*, two first leaves after the cotyledons; R, primary root; *r*, lateral root; *t*, ruptured testa. (The cotyledons are enclosed within the testa.)

succession. Observe, also, that they form rows (commonly four in the Kidney Bean) on the main root.

In older plants make corresponding observations on the lateral roots.

Roots, especially of Biennial plants, often become thickened and succulent.

Examine the tap root of a Carrot or Turnip. In the former the shape of the tap root is called **Fusiform** and in the latter **Napiform.**

The tuberous roots of Asparagus should also be studied. Observe that the fleshy tubers are the swollen parts of **roots**, but that not all the roots swell in a similar manner. The same may be observed on the Sweet Potato (**Ipomoea Batatas**).

Dig up some plants of the common Spotted Orchis, and note the tuberous bodies upon it. Determine that these are also modified roots.

Roots which originate not as branches from the tap or other roots, but from stems, on which they arise in no very definite order, are termed **adventitious** roots.

Examine a creeping stem of Oxalis and observe several of these spring from a node of the stem.

Sometimes roots are used to facilitate climbing. Examine a climbing shoot of the Betel Vine (**Piper Betel**) and observe on the shaded side directed towards the support, that a line of adventitious roots are formed in this way, and that they are not confined to the nodes.

Cut off the twig of the Betel Vine from its main stem but leave it attached to the wall by its roots. The twig will, nevertheless, die; the roots are not primarily concerned with supplying the plant with food or water, but serve to attach it to the wall.

Dig up a plant of Clover or Bean or some other leguminous crop. Note the **nodular swellings** which occur irregularly on the roots of these plants. They are produced by the invasion of a lowly organism, but the

plant is able, by means of these organisms, to obtain an important food-element (nitrogen) from the uncombined nitrogen of the atmosphere. Plants which have not these nodules on their roots are unable to utilize the free atmospheric nitrogen.

Hairs and Emergences.—Many plants produce hairs over their surface. These hairs will be found to arise only in the outer cell-layer of the organ which bears them.

Hairs may be observed on nearly all our common plants, those destitute of hairs (**glabrous**) being few in number.

Hairs occur on the young parts of roots, and they serve as the means by which roots absorb water from the soil.

For examples of hairs, examine young twigs of Cucurbita, the Stinging Nettle, and other hairy plants. The stinging hairs of the Stinging Nettle are situated upon a somewhat solid base. Hairs are always developed from superficial cells. When they are unicellular, they are termed **simple** and when multicellular, **compound**, or **articulate.** These may be branched or unbranched. When hairs are stiff, they are termed **bristles.**

Emergences, in which the outgrowth is more bulky than the hair, and the deeper-lying parts of the organ enter into its formation.

The simpler forms of the emergences are **Prickles** and **Warts.** The more specialized forms are the **Tentacles,** e.g. in Drosera, the **Ligules,** e.g., in Grasses, and the **Corona** of certain flowers.

Many highly developed emergences frequently contain vascular tissue.

Note, again, the tentacles of the Sundew: these are emergences, and their complicated structure can at once be distinguished by looking at them with a strong lens against the light.

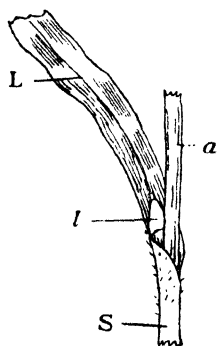


FIG. 28.—Leaf of grass. S, leaf sheath; L, leaf blade; l, ligule; *a*, axis.

Emergences often take the form of prickles, which may be obviously useful to the plant. Study the form and use of the prickles in the Rose and the Blackberry.



FIG. 29.—Prickles on the Stem of a Rose.

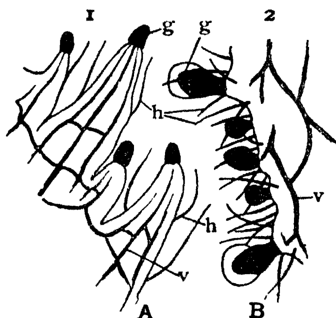


FIG. 30.—**A**. Glands (*g*) on the teeth of the leaves; *v*, vascular bundles; *h*, hairs. **B**. The same on the margins of the stipules.

Observe the base of the prickle. Its form is adapted to resist its being readily torn off by a pull in the direction of the branch. But it can easily be detached by bending it to the right or left.

Note the clean scar left when it is broken off.

Other examples of emergences are the attachment organ or **Hapteron** of some Ampelideae and others; also the suckers or **Haustoria** of Cuscuta, Orobanche, etc.

CHAPTER IX

INFLORESCENCES

HITHERTO our attention has been restricted chiefly to vegetative shoots. We will now consider flowering ones, with special reference to their modes of branching.

A flower is simply an axis, or branch, the last borne leaves of which are modified for purposes of reproduction. And with the appearance of these modified leaves, the further growth of the branch commonly ceases.

The main shoot of a plant, after bearing vegetative leaves, may finally end in a flower as in the Red Poppy **(Papaver rhaeas)**, Lotus or Crocus; the axis of growth being undertaken by a lateral vegetative shoot, or the flowers may arise exclusively as the lateral branches of a main axis, which continues to grow for an indefinite length, as in the Gold Mohur, the Delphinium, Mustard and the Foxglove. The **Inflorescences** (groups of flowers) on plants are thus divided into **Cymose,** or **Definite,** and **Racemose,** or **Indefinite,** types.

Take a flowering plant of **Brassica nigra,** or **Cleome viscosa** and observe that the flowers are arranged as lateral branches, developing in acropetal order, of an indefinitely growing main axis. These are thus Racemose inflorescences. The flower-stalks are known as **pedicels,** the main axis as the **peduncle.**

Further in **Cleome viscosa** note that the **bracts** (the axillant leaves of the flowers) are arranged in the same phyllotaxis as those on the rest of the leaves on the plant, and that in the lower part of the inflorescence they may quite resemble these leaves, whilst those higher up are more reduced and rudimentary in form.

Next examine the racemose inflorescence of Candytuft **(Iberis amara)** or Gynandropsis.

Note that the pedicels which arise on the peduncle are not equal in length, those of the outer (older) flowers being elongated, so as to bring the blossoms to a somewhat level head. This form of raceme is known as a **Corymb.**

Examples of Corymbs may also be seen in Cassia, Caesalpinia, Ixora, Alyssum.



FIG. 31.—Calotropis gigantea (*Akand*).

Next examine the flowering branches of Calotropis and Sepiaria. You will find that the flowers are borne in groups of heads ; take one of these heads, and observe—

1. That the flowers arise at almost the same level.
2. That there are few or no bracts where the flowers arise.
3. That the outer flowers open first.

This is a type of that variety of racemose inflorescence known as the **Umbel.**

Compare the flowering heads of Foeniculum, Coriandrum, or **Daucus Carota** with Calotropis and note that at the summit of the main peduncle a number of branches arise, but that these do not terminate at once in flowers, but each branches once more, forming secondary umbels. Otherwise the inflorescence is similar to Calotropis.


FIG. 32.—Daucus Carota (*Carrot*).

Observe the presence or absence of bracts.

The inflorescences may be readily explained by supposing that the internodes of the peduncle have been so shortened that the flowers have come to spring out in the umbellate manner, owing to the close approximation of the nodes, which can no longer be distinguished from each other.

Next take a spike of Callistemon or Plantago, and observe—

1. The stout central peduncle, with the older flowers at the base and the younger ones at the apex.
2. The flowers themselves are sessile on this peduncle, i.e. the **pedicels** are almost suppressed.
3. The bract below each flower. [This is absent in some plants which otherwise resemble the Plantain in their inflorescence.] Note its form and character.

Inflorescences of this kind, in which the flowers are distributed in a sessile manner on an elongated peduncle, are called **Spikes.** Also found in **Polyanthes tuberosa, Spinacia oleracea,** etc.

Examine the inflorescence of the Common Arum (**Arum maculatum**).

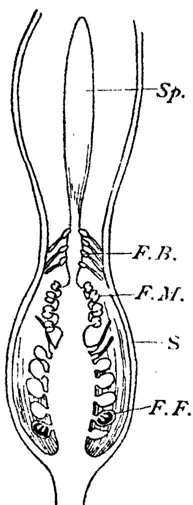


FIG. 33. — *Arum maculatum*. Section of inflorescence (slightly diagrammatic). S, spathe; *F.F.*, pistillate flower; *F.M.*, male flower; *F.B.*, hair-fibre structure (probably barren flowers). *Sp.* naked part of spadix.

Observe—

1. The large sheathing structure, which opens at one side when mature, and which is tightly rolled round on itself when young. This is the **Spathe.**
2. Within this the curiously shaped inflorescence, forming bands near the base of the swollen axis. Such a swollen axis is called a **Spadix.**
3. The lower band of flowers is female. The upper one is composed of rudimentary male flowers; whilst above these latter there is further a zone of curious hairs.
4. The naked club-shaped axis, which is much narrowed above the zone of hairs just mentioned.

A case of **Compound Spadix** is found in Date Palm (**Phoenix dactylifera**). Here the fleshy axis of the inflorescence is repeatedly branched and the branches bear sessile, unisexual flowers. The whole inflorescence when young, is enclosed in a spathe.

When a spike is pendulous and consists of unisexual flowers, which fall off as a whole, it is called a **Catkin**, e.g., Morus, Salix, Populus, etc.

Next take a Sonchus or Centaurea and Sunflower.

In Sonchus, note the hollow peduncle, and that when it is cut across, a milky juice (**Latex**) exudes from the cut ends.

Note the dark-green bracts at the base of the 'flower.'

Within these it will be found that what appear to be yellow petals are really **flowers.** Each flower is directly inserted (sessile) on the white expanded surface formed by the top of the peduncle. Inflorescences of this kind are termed **capitula.**

Be careful to notice that the central flowers (as in an umbel) are the youngest.

In the Sunflower, observe—

1. That it is enclosed by a zone (or **Involucre**) of bracts, as in the Sonchus.
2. That the outer flowers are much larger than those placed more centrally, and that they differ from them in shape.
3. That each of the flowers has a membranous bract situated on its outer side.

The youngest flowers are situated towards the centre of the head, i.e., they develop in acropetal succession, just like those of an ordinary raceme.

Thus, it will be seen that the umbel stands midway between the ordinary raceme and the capitulum.

In the former the peduncle is telescoped ; in the latter, in addition to this, the pedicels are suppressed, as in the Plantago.

Thus the capitulum combines in itself the essential features of both the umbel and the spike. It sometimes happens in racemose inflorescences that the flowers are only developed on one side of the main axis. [This usually is the result of lack of room for the flowers to form on part of the stem whilst the whole inflorescence is still in a very young condition.]

Some racemose inflorescences are **compound** ; thus the branch in the axil of a bract may not develop directly into a flower, but itself bear flowers. This we have seen to be the case in many umbel-bearing plants.

Examine the inflorescence of the Oat.

The flowers are minute, and are arranged in spikes at the end of rather long branches, which are grouped in

loose racemes. The whole inflorescence is termed a **panicle** of spikes.

Similarly, the Rye-grass is an example of a compound inflorescence, a spike of spikes.

Compound capitula are found in the flower heads of **Echinops echinatus**, where each capitulum consists of a single flower surrounded by an involucre of bracts. In concluding the racemose types of inflorescence mention may be made of the **Hypanthodium** or inflorescence of the Figs. Here the capitulum forms a hollow globular structure having a hole at the top. The flowers are arranged all over the inner surface and are unisexual and minute. The male flowers are situated near the mouth of the cup and the female flowers occupy the space below. Examples in all the species of Ficus.

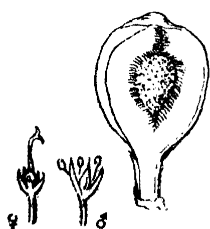


FIG. 34.—*Ficus carica*, inflorescence and male and female flowers.

CHAPTER X

INFLORESCENCES—(Continued)

Cymose Inflorescences.—As already mentioned, in this type, the primary axis or the rachis ends in a flower and its growth is therefore stopped. When other flowers arise upon the axis, they come out from the lateral axillary buds below the apex. Usually each axis bears just one, or two or sometimes a few branches which grow more vigorously and overtop the main one.

These lateral branches terminate in flowers and repeat the same form of branching. The terminal flower of the main axis opens first and is followed by those terminating the secondary, tertiary and other axes in regular sequence. The order of flowering in this type is from the apex to the base (**Basipetal**) and the inflorescence is described as **Definite** or **Centrifugal** as opposed to the **Indefinite** or **Centripetal** inflorescence in the racemose type.

Take the flowering twigs of Ixora or **Saponaria vaccaria,** a common wild herb. Observe—

1. That the main axis ends in a flower. This is the essential character common to all cymose inflorescences.
2. That in the axils of the topmost pair of leaves, just below the flower, two branches arise which similarly end in flowers.
3. That the opposite and decussate phyllotaxis is continued on the lateral branches.

The above are examples of **Dichasial** cymes. In Saponaria the inflorescence by sterility of one of the leaf axils in each pair, passes over to the **Monochasial** type of Cyme. Other examples of Dichasial Cymes are **Althæa rosea, Jatropha multifida, Dianthus chinensis,** Clerodendron, etc.

Next examine the inflorescence of Borago or Heliotropum and observe that the flowers are on the upper side of an elongated branch, and that they form two rows, and that the leaves occur in two rows on the under surface. The apparent branch is a **Sympodium** (joint-axes) and the whole forms a cymose (monochasial) inflorescence, often termed a **Scorpioid** Cyme or **Cincinus.** Observe that the end of each sympodium is rolled in. This is very common in scorpioid cymes.

These scorpioid cymes are very common and are often rather difficult to understand, and great care must be exercised in making accurate diagrams.

Now examine the inflorescences of Hemerocallis or Hypericum, and note that the main axis ends in a flower and the lateral branches develop only on one side in a regular manner and the other one being regularly suppressed on the other side. This type of inflorescence is known as a **Helicoid** Cyme or **Bostryx.**

Besides the Dichasial and Monochasial Cymes, we find **Polychasium** as in many Euphorbia where more than two secondary branches are given off from the main axis, below each flower of the inflorescence.

Now examine inflorescences of Ocimum and Salvia and note that we have exactly the same type, starting as a dichasium, and passing over on both sides of the middle (and oldest) flower into two monochasia.

But the matter is complicated by the fact that the flowers are sessile, and the bracts very difficult to trace. An inflorescence of this kind is often called a **Verticillaster,** as the two opposite clusters in the axils of the two foliage-leaves seem at first sight to form a whorl. You have seen, however, that this is not really the case.

Another type of cymose inflorescence is met with in the Rose and in the Buttercup family.

Examine the upright flowering stem of the Meadow Buttercup. Observe that the main axis terminates in a flower, but that it bears on its stem a number of leaves

in the axils of each of which a flowering shoot may arise. Note, first, the order in which the flowers of a Buttercup plant open, and their positions with regard to one another. Carefully observe that, as regards the large shoots springing from the axils of the cauline leaves, that the uppermost lateral shoot opens one or two flowers first; then the flowers on the next lower shoot begin to open; and so on: thus these flowering shoots mature, not acropetally, but **Basipetally** (= developing towards the base). You will readily detect the cymose character of the inflorescence, since the main axis ends in a flower; the same character is also (as has been stated) repeated in the flowering sprays arising from the axils of its lower cauline leaves.

Inflorescences as exemplified by the Buttercup and the like may be termed **Cymose corymbs.**



FIG. 35.—The Teazle (*Dipsacus sylvestris*). A, young, B, older, inflorescence.

Just as we may have Cymose and Racemose corymbs, so we may have Cymose and Racemose umbels.

Examine a Crinum or a Scarlet Geranium inflorescence. It will be found that the flowers at first sight appear to be grouped in umbels, but the irregular arrangement of the expanded and unopened flowers in the cluster causes one to suspect that again we are not dealing with

a racemose type. And, in fact, the Geranium inflorescence is essentially similar to that of the Buttercup, save that the pedicels all spring out together from the peduncle, and a **Cymose umbel** is the result.

In many plants we meet with **mixed inflorescences.**

Examine the Horse Chestnut inflorescence, and make out that it is a raceme of scorpioid cymes. Similarly determine carefully the nature of the inflorescence in the Lilac.

Examine the remarkable inflorescence of the Teazle (**Dipsacus**). The flowers are arranged in dense heads, and the first ones to open are situated in a zone about the middle of the head. Observe, in slightly older inflorescences, how the flowers develop in **two** diverging zones. One set of flowers open towards the apex (acropetal), the other towards the base (basipetal), of the head.

CHAPTER XI

THE FLOWER

As the first example of a flowering shoot, we will take **Ranunculus sceleratus**, which is a fairly common weed, but any other species will do as well and may be chosen for comparison with the type described.

Observe that the leafy upright branch **ends in a flower.**

It frequently produces leaves below the terminal flower, in the axils of which other floral branches arise.

In the flower, notice—

1. The five rather hairy **Sepals**, their colour and arrangement. They form the outermost parts of the flower, and are more like leaves than the inner and more modified leafy structures. Observe that they are all separate, and are arranged in a phyllotaxis of $\frac{2}{5}$. Observe the character of the margins of the sepals.
2. The five smooth or glabrous **Petals**. (In luxuriant specimens the number may be greater.) Observe that they are also free, and that they alternate with the sepals. Make out the arrangement (phyllotaxis) of the petals amongst themselves. Observe a scale-like swelling at the base of each petal, and the small pouch-like opening directed towards the apex. This is the **Nectary**. Compare the nectaries of this plant with those of other common species of Buttercup.
3. Passing inwards, observe the numerous **Stamens**, all separate, or **free**. The group of stamens, taken together, constitutes the **Andrœcium**. Make out in each stamen the **Filament**, the **Anther** and **Pollensacs**, and the **Connective**. Observe the form

of the filament—a somewhat flattened structure, broader below. Notice, also, the way in which the anther is situated upon the filament. (In this plant it is basifixed.) [Is the anther **adnate, innate,** or **versatile ?**].

When the anther is not sharply marked off from the filament and is attached throughout its whole length to the filament, it is **Adnate.** When it is sharply marked off from the filament but fixed by the base it is **Innate.** When the filament is inserted in the middle of the dorsal surface of the anther and is articulated as by a joint, the anther is said to be **Versatile.** If the filaments are very short or absent the anthers are said to be **Sessile.**

Further observe that the stamens are not all at the same stage of development: some are opening to let out the dusty yellow **Pollen,** whilst others (higher up) are still immature. Determine the way in which the **Dehiscence** (opening) of the anther is effected. [Is the dehiscence **extrorse** or **introrse** ?]

If the pollen is shed towards the centre of the flower, it is **Introrse,** if towards the periphery **Extrorse.**

4. In the centre of the flower notice the numerous separate **Carpels,** each distinct from the rest. The group of carpels taken together constitute the **Pistil,** or **Gynæcium.** Observe in each carpel—

   (*a*) a stalk, or attachment to the stem;
   (*b*) a swollen portion, the **Ovary**;
   (*c*) a rather sharply curved **Style,** very short, which ends in—
   (*d*) a **Stigma,** which in this plant takes the form of a velvety or brush-like surface near the end. Observe how readily the pollen grains adhere to the stigma when the flowers are well opened. (This can easily be seen with a strong hand lens.)

Pick off one of the carpels, and with a razor or a sharp knife cut it down the middle, keeping the knife parallel to one of the flat sides of the carpel. Observe the single **Ovule** attached close to the base of the inside of the carpel. Examine it with a lens, and determine—

1. Its shape.
2. The exact place of its attachment. Note the **Stalk** (funicle), and observe that the stalk closely adheres, in all but its lowest part, to the swollen **Nucellus** of the ovule, forming the **Raphe.**
3. The position of the **Micropyle,** or the hole in the integuments which cover the nucellus.
4. The character of the integuments. The spot at which they are attached, at the base of the nucellus, is termed the **Chalaza.** The two last features are best seen by immersing the ovule in water on a piece of glass, and covering it with another piece and gently squeezing it. These observations will lead to the conclusion that the ovule is **Anatropous,** i.e., becomes bent on the stalk so that the micropyle comes to be nearest to the placenta. Instances of anatropous ovules are very common.

[Sometimes the ovule not only becomes bent back on its stalk but also curved, when it is termed **Campylotropous.** Instances are found in Bean, Gram and many other plants. When as in the Antigonon and others of the Polygonaceae, the funicle, chalaza and the micropyle are all in a straight line, the ovules are described as **Orthotropous.**]

Take another flower, and cut it into two similar halves down the middle. Observe—

1. That the floral organs are situated upon a swollen end of the branch; this end forms the **Floral receptacle,** or **Thalamus.**
2. That each whorl is distinct from the rest, and is inserted directly on the thalamus (**Thalamifloral**).

3. That all the whorls succeed each other acropetally, and that the gynæcium is situated above the stamens (**Superior**), and hence the outer whorls (stamens, etc.) are Inferior, or **Hypogynous.**

Examine a flower-bud about to unfold. The arrangement (**Æstivation**) of the parts is then easily recognized.

Examine a floral branch which has lost its three outer sets of organs, and only retains the ripening gynæcium, or **Fruit.** Carefully compare the form of a carpel with that of younger specimens.

Cut the carpel down the middle, and observe that the carpel-wall has become converted into a rather hard shell (**Pericarp**), which contains the single **Seed** (ripened ovule). This fruit is known as an **Achene.**

Pick out a seed, and with needles [N.B.—It is better to soak the fruits for a night in water to soften them before cutting or dissecting them] dissect off the **Seed-coat,** or **Testa** (derived from the ovular integuments), and observe the white **Endosperm,** or **Albumen.** In the albumen lies the small embryo, which with some difficulty can be seen to possess two seed-leaves (**Cotyledons**) at one end and at the other, which is directed towards the micropyle, the **Radicle** ending in the root can be plainly distinguished.

The foregoing observations will teach us that the Buttercup—

1. Contains the four sets of floral organs—calyx, corolla, stamens, and ovary or pistil; and that it is therefore a **Complete,** or **Perfect** flower.
2. The flower is radially symmetrical, or **Actinomorphic** or Polysymmetrical. (Symmetrical flowers which can be divided into equal and similar halves by one vertical plane only is called **Zygomorphic** or Monosymmetrical, e.g., Pea flower.)
3. It possesses both stamens (forming the andrœcium) and pistil (gynæcium), and is hence **Hermaphrodite.**

4. That sepals, petals, and stamens (and the carpels also) are all **Free**, and not directly united in any way with each other, and are **Hypogynous.**
5. All the whorls are inserted directly on the thalamus, and the flower is thus **Thalamifloral.**
6. That the pistil (gynæcium) is situated at the top of the flower, the other whorls being inserted below it ; thus the flower is said, with regard to the relative position of the gynæcium to the rest of the flower, to be **Superior.**
7. The presence of nectaries in the flower show that it attracts insects for the purpose of conveying the pollen of one flower to the stigma of another, and it is hence said to be **Entomophilous.**
8. The fruit is one-seeded, dry, and indehiscent, i.e., it is an **Achene.**
9. And owing to the presence of endosperm (sometimes called **albumen**), the seed is said to be **Albuminous.**
10. Finally, because the embryo possesses two cotyledons, the plant is said to be a **Dicotyledon**, a conclusion confirmed by the net-like veining of the leaves.

Next examine the flower of a Cherry or Plum tree, make out the following points :—

1. That the calyx, corolla, and andrœcium are borne on the rim of a cup-like structure—the '**Calyx-tube**,' and are, apparently, not directly inserted on the receptacle.
2. That the ovary is situated at the bottom of this cup, but at the top of the thalamus or receptacle.
3. That consequently the outer floral whorls are situated **around**, and not under, the gynæcium. Hence the flower is said to be **Perigynous.** It is also **Calycifloral**, on account of the insertion of the stamens upon the calyx-tube.

Compare with the foregoing the flower of the Sweet Pea (**Lathyrus odoratus**). Note that the flower is also perigynous. The corolla is irregular and the symmetry is **Zygomorphic.** Examine the stamens carefully and note that, of the ten stamens, nine are united into a bundle and the tenth is free, so that the stamens are in two bundles, nine and one (**Diadelphous**). Compare with this the stamens of Orange and note that the numerous stamens are grouped in several bundles (**Polyadelphous**).

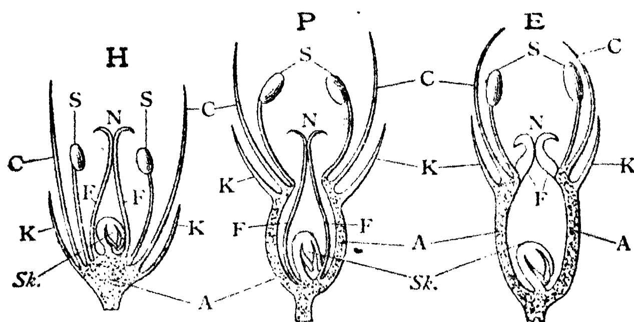


FIG. 36.—Diagrammatic section of hypogynous (H), perigynous (P), and epigynous (E) flowers. A, axis, forming convex or concave receptacle, or wall of ovary; K, calyx; C, corolla; S, stamens; F, carpels; N, stigma; *Sk*,. ovules (After Prantl.)

Finally, pick out one of the central flowers of a Sunflower. Cut it also down the middle, and examine the relations of the different whorls to each other.

You will notice that—

1. The ovary is situated at the base of the flower, and the outer whorls are all inserted above it, apparently rising upon it; that is, they are **Epigynous.** Hence the ovary is said to be **Inferior.** The style and forked stigma alone rising up in the centre of the flower.
2. The petals also are united into a tube, or, as it is termed, are **Gamopetalous,** though their number may be determined by the five distinct lobes.

3. The stamens are inserted upon the corolla (alternating with the lobes of the corolla), and thus are said to be **Epipetalous,** and the flower is said to be **Corollifloral,** and it is also, as we have already seen, **Epigynous.**
4. There is no ordinary calyx, but two membranous leaves arise below the corolla on the top of the ovary, which may perhaps be taken to represent the sepals.

Compare the flower of **Eugenia Jambolana** with that of the Sunflower. Note the calyx of five sepals united (**Gamopetalous**). Corolla of five petals, free (**Polypetalous**). These arise from the margin of the thalamus tube as the sepals; so also the indefinite stamens. The pistil of two carpels, united (**Syncarpous**). Carefully notice that the wall of the ovary is fused with the thalamus tube and so actually below the other whorls, hence **Epigynous.**

We thus see that there may exist considerable differences in the relations both of the floral whorls to one another, and also in those of the members of the same whorl to each other. We shall study this more fully later on.

CHAPTER XII

THE FRUIT.

THE essential facts in connection with the fruit which we have to determine are these :—

1. Whether it originates from a single carpel, or at any rate from a number of isolated carpels (apocarpous), or from carpels which are joined together (syncarpous).
2. Whether it is dry or succulent.
3. Whether it is dehiscent or indehiscent.
4. Whether it is formed from a superior or an inferior gynæcium.

Examine the fruit of the Pea. In this and in the following plants, specimens should be taken which will enable you to construct the history of the fruit from the flowering stage.

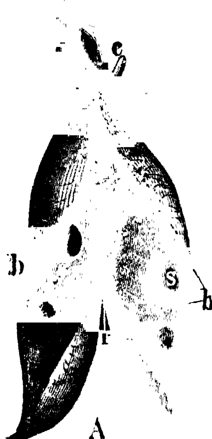


FIG. 37.—The Pod (legume) of the Pea. *r*, the dorsal suture; *b*, the ventral; *c*, calyx; *s*, seeds.

Observe—

1. That the fruit is formed from a single carpel.
2. That the carpel wall (or **pericarp**) is succulent, whilst the fruit is young, but becomes **dry** when it is ripe.
3. That it possesses two well-marked sutures, one dorsal and one ventral, and that the seeds are arranged on the slightly swollen placenta inside the ventral suture.
4. That the fruit when ripe dehisces by both sutures.
5. That it is formed from a superior gynæcium.

This fruit is termed a **Legume.** Compare with the legume of the Pea that of the **Bean.**

Next compare with these the fruit of **Calotropis gigantea** or **Nerium odorum.** Observe—

1. That the fruit consists of two carpels which are distinct.* Ascertain the position of the ovules.
2. That the pericarp is dry.
3. That of the two sutures, only the ventral one opens. Carefully note the **form** of the dehisced carpel. Carpels which dehisce by the ventral suture only are termed **Follicles.**
4. That it originates from a superior ovary.

The whole fruit thus consists of a **collection** (or **etærio**) of **follicles.**

Compare the fruit of the Buttercup with that of these last-mentioned plants.

Observe that it, also, consists of many free carpels (i.e. is apocarpous), and that each contains a **single seed.**

The pericarp is dry in the ripe fruit, and it does not dehisce to set the seed at liberty.

The whole fruit is thus **a collection** (or **etærio**) of **achenes.**

Compare the fruit of Clematis with that of the Buttercup. It will also be found to be an etærio of achenes. Observe the long bearded and persistent style.

Next examine either the fruits of tomato or grapes. Observe—

1. That it is (unlike the ripe Pea) succulent.
2. That it is indehiscent.
3. That it is formed from a superior gynæcium. You will observe that the pericarp is distinguishable into a membranous skin, and that the rest of the carpel wall, together with the placenta, forms the pulp.

This fruit is termed a **Berry.**

Carefully compare it with the fruit of the Pea, and note the points of resemblance and difference.

Next examine a Mango fruit. Observe—

1. That, like that of the tomato and grape, it consists of a single carpel.
2. That it is also succulent, but that inside the flesh is a stone. This stone is derived from the inner layers of the pericarp, and the seed lies inside it. Therefore, the pericarp here forms—
   (*a*) An outer thick skin—the **Epicarp.**
   (*b*) A middle, fleshy portion—the **Mesocarp.**
   (*c*) An inner stony layer—the **Endocarp.**

Cut some mangoes which are half-grown, and trace the formation of these layers.

3. That it is indehiscent, but that when ripe the epicarp and mesocarp rot away, leaving only the hard endocarp. This only ruptures when the seed germinates.
4. That it is formed from a superior gynæcium.

This kind of fruit, with a pericarp distinguishable into three layers, is termed a **Drupe.**

Compare the fruit of the **Blackberry (Rubus)** with that of the Buttercup. Very carefully examine the little fruitlets at different stages of ripeness. You will observe—

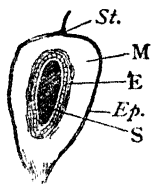


FIG. 38.—Blackberry (*Rubus fruticosus*). Diagrammatic longitudinal section of one of the drupels of the fruit. E, endocarp (of two layers); *Ep.*, epicarp; M, mesocarp; *St.*, withered remains of style and stigma.

1. That the fruit is apocarpous, consisting of many free parts.
2. That the pericarp of each is differentiated into three layers—
   (*a*) The **Epicarp,** a membranous layer.
   (*b*) The **Mesocarp,** which constitutes the pulp.
   (*c*) The **Endocarp,** which forms the 'stone.' Note the seed lying protected in the cavity formed by the endocarp.

Thus the fruit is succulent.

3. That it is indehiscent.
4. That the gynæcium is superior.

This fruit consists of a collection (or etærio) of **drupels**, one drupel being derived from each carpel.

Compare the Mango with the Blackberry. The chief essential difference lies in the fact that the gynæcium consists of a single carpel in the Mango, and of a number of apocarpous ones in the Blackberry.

Compare the **Strawberry** with the Buttercup.

It is essential to examine various stages in the development of this fruit. Determine carefully from what the pulp in the strawberry originates, and also what structures correspond to the achenes of the Buttercup.

Examine the **hip** of the Rose. Cut it down the middle, and observe the hard hairy achenes enclosed within the fleshy receptacle. This has grown up, and on it were inserted the calyx, corolla, and stamens. But the carpels lie on the inside of the cup. By following the history from the rosebud stage you will see how it has been effected.

The achenes form the true fruit, and the coloured and fleshy receptacle (as in the Strawberry) forms an accessory structure.

Let us now examine the fruit of the Common Cotton Plant (Gossypium).

Cut a transverse section of the half-ripe fruit, mount it in a drop of water, and look at it through a lens.

Observe the number of cavities. Each one corresponds to a carpel.

Note the position and form of the placentas, and the arrangement of the unripe seeds on them. Make a diagrammatic sketch to show the relation of the various parts to each other.

In the ripe fruit observe that the pericarp becomes dry. Determine the mode of dehiscence of the fruit (along the loculi, i.e., **Loculicidally**).

Does it arise from a superior or inferior gynæcium?

Compare the fruit of the Abutilon with that of the Cotton.

Observe the number of carpels and method of dehiscence. Note, also, that there are as many distinct styles as there are loculi to the fruit.

Next examine and cut transversely the fruit of the Violet or Pansy. Note especially the position of the placentas and the method of dehiscence. Carefully compare this fruit with that of the Cotton as regards its dehiscence.

Next examine the fruit of **Datura Stramonium**, comparing specially the younger and the older stages which can easily be obtained on the same plant.

Observe—

1. That the two-celled connate carpels become spuriously four-celled by development of accessory septa from the placentas.
2. That the fruit opens by four valves between the septa, from above downwards leaving the septa and the placenta in the middle **(Septifragally)**.

Examine the fruit of the common Celosia or Plantago or Hyoscyamus and pay special attention to the dehiscence. The dehiscence here is transverse, i.e., opens by a lid. The capsule is known as **Pyxidium**. Examine the Poppy capsule. Note the peculiar method of dehiscence by pores. Also the position of the stigmas.

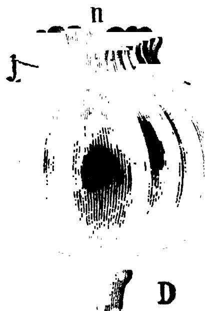


Fig. 39.—Capsule opening by pores of Poppy. *n*, stigma; *i*, the pores which open only by the removal of the valves *a*.

Compare with the Poppy fruit the capsule of Campanula and observe the method of its dehiscence by means of the windows formed in the carpel walls.

Examine the fruit of the Flax **(Linum usitatissimum)**. Observe that there are twice as many divisions as there are styles and stigmas. Every other septum is formed by an ingrowth from the midrib of the carpel. Carefully

compare the fruit with the ovary of the Flax when still in flower. Note the method of dehiscence of the ripe capsule (**septicidally** into 5 simple 2-seeded, or 10 one-seeded cocci).

Examine also the fruit of Rape or Mustard. The fruit is called **Siliqua.** It consists of two coherent superior carpels, originally one-celled but rendered two-celled by the growth of a spurious dissepiment called **Replum.** When ripe, note that it dehisces into two valves from the base upwards, leaving their margins with the parietal placenta bearing seeds. When the siliqua is short and compressed as in the fruit of Shepherd's Purse, it is called **Silicula.**

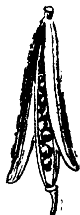


Fig. 40.—A siliqua.

Now compare with the foregoing, the fruit of Balsam. Observe that the ripe carpels spring from the axis, and the seeds are flung out.

Carefully watch the mechanism, and, if you choose a sunny day about noon, you can follow out the process by lightly touching the ripe fruits with a small camel's-hair brush.

Next we may mention the so-called **Pome** of the Apple and Pear. This fruit is best studied in connection with the Rosaceæ, and will not be further considered here.

Next consider the fruit of **Trapa.** Observe that it is a large ovoid bony **Nut** with 2 or 4 prominently spinescent angles, and that the carpels are inferior and syncarpous. (Note the Walnut is **not** a **Nut.**)

The fruit of the Wheat may next be examined. This is also formed from a (probably) bicarpellary gynæcium ; and so closely does the single ovule adhere to the ovary wall, that no trace of the testa can be distinguished in the ripe fruit. It is on this account designated as a **Caryopsis.** It is indehiscent, and is really a form of the achene.

Examine the fruit of the Sunflower or of a Dandelion This you will find to arise from an **inferior** gynæcium,

and, relying on the two stigmas, the latter is considered to be bicarpellary. It is indehiscent, and forms that variety of the achene termed the **Cypsela.** Note in the Dandelion the beak surmounted by the pappus.

The fruit of Trapa, Wheat, and Dandelion are thus very similar to that of the Buttercup, but the pericarp is formed of more than one carpel.

Some indehiscent fruits, although they do not liberate the seed from the ovary, split up into as many parts as there are carpels.



FIG. 41.—A. Cremocarp of the Fennel. *a*, Carpophore. B. Bipartite schizocarp of the Maple, consisting of two samaræ.

Examine the fruits of Castor-oil plant, Sida, Heliotropium or Malva.

Carefully study the way in which the splitting is effected. The parts are each termed a **Mericarp,** while the whole fruit before division is a **Schizocarp.**

The fruit in which the pericarp expands into one or more flat limbs or wings, is known as **Samara.** Examples are found in Hiptage, Maple, Sycamore. In the last two the fruits are schizocarpic.

There are a few other forms of fruits which require special care.

Examine a very young Fig. You will find on cutting it down the middle that it contains a large number of small **flowers.** Each of the flowers may give rise to an achenial fruit.

The succulent part of the Fig is, then, the swollen inverted part of the inflorescence axis. Imagine that the

flat top of a Sunflower head on which the flowers are borne was hollowed out like a cup, that the flowers were sunk in it, and that then it became succulent, and you would have something like a Fig.

Carefully note the difference between such a fruit and a Rose hip; the former is an inflorescence, the latter is derived from a single flower. Fruits like that of the Fig are really multiple fruits.

Next examine the fruit of a Mulberry. Superficially this resembles a Blackberry; but it will be seen on closer study to represent an inflorescence. The real fruits are drupes, which, however, are enclosed in the persistent succulent calyx. The Mulberry and the Pineapple are also examples of multiple fruits.

CHAPTER XIII

THE STRUCTURE OF SEEDS—GERMINATION

[In preparing seeds for study, it is generally best to soak them in water overnight; this renders them softer, and easier to dissect.]

HAVING become familiar with various kinds of fruits, we will next examine a few seeds.

Take the seed of the Bean or Pea. Observe its form. Note the blackish **Hilum.** Squeeze the soaked bean. Notice that at one point, close to the hilum, you can force out a drop of water. This spot marks the **Micropyle.**

Dissect off the seed-coat, or **Testa.** The whole of the inside will be found filled with the embryo. In the embryo make out—

1. The **Cotyledons.**
2. The **Plumule,** the small curved rudimentary bud lying between them.
3. The **Radicle,** with its end portion, the **Root,** directed to the micropyle.

Examine the seed of the Sunflower. You will have to dissect off the thick **Pericarp in** which the seed is enclosed. Having done this, observe that—

1. The seed-coat (testa) is thin and membranous.
2. The embryo completely fills the seed.
3. The embryo is made up of plumule, two cotyledons, and the radicle.

Compare with the two foregoing the seeds of Ispagoola or of the Cress. Make out the raphe running along one edge of the seed, and terminating at the hilum. Notice that the seed-coat swells and becomes slimy in water.

Cut a section through a dry seed, and mount it in a drop of water. You will see that the mucilage is only derived from the outer layer of the testa.

Dissect the seed, and observe the embryo completely fills the seed. Carefully observe its form, and the manner in which its radicle is disposed relatively to the cotyledons. Make similar observations with Mustard and Citrus seedlings.

The seeds we have so far examined are, at least when ripe, destitute of albumen, i.e., they are exalbuminous.

Next take the seed of Poppy or of the cultivated Viola or Pansy. Note the form of the seed, and the position of the hilum, and the presence of the raphe.

Dissect away the seed-coat, and observe—

1. That the embryo is small, and does not fill up the seed-cavity.
2. That this space is occupied by **albumen** or **endosperm.** Observe the position of the embryo as regards the endosperm.

A much easier seed in which to observe endosperm is that of Ricinus or of Buckwheat. Examine also one of the mericarps of the fruit of Carrot, Fennel, or any other umbelliferous plant. Dissect away the pericarp; this is not easy, as the membranous testa adheres to the pericarp. Observe that here, also, the seed contains both an embryo and albumen, or endosperm. Thus the seeds of the three last-named plants are all albuminous.

Next get some **ripe** seeds of the White Water Lily **(Nymphæa alba).** Observe that the seed is contained in a small sac-like outgrowth from the base, i.e., the top of the funicle. This is the **Aril** (Cf. arillode of Euonymus). Remove this, and carefully dissect away the hard seed-coat, and cut the enclosed contents from top to bottom.

Observe—

1. The large amount of **perisperm,** which has been derived from the nucellus of the ovule.
2. The endosperm (easily confounded at first with an embryo) lying near the pointed end of the seed.

3. The minute embryo lying in the endosperm.

[The seed of the Canna (a monocotyledon) may be compared with the Water Lily; in it there is no endosperm, the embryo fills the embryo-sac; the latter is very small in comparison with the perisperm, which fills up the rest of the seed.]

Hitherto we have only studied the seeds of Dicotyledonous plants, we will now turn to Monocotyledons.

Examine the fruit of the Wheat. Observe its form. The pericarp cannot be separated from the testa (which is nearly absent in the ripe fruit) in the Wheat. Observe **the Embryo,** situated near the blunt end of the seed on the rounded side. Carefully dissect it out. Compare it with early stages of germinating Wheat. (These may be obtained by soaking the grains and keeping them on wet blotting paper for a day or two).

In the soaked grains observe—

1. That the embryo is outside the albumen.
2. That the albumen, or endosperm, constitutes the chief part of the grain.

Cut longitudinal sections of the grain, and make out with the aid of a lens—

1. The Pericarp, as a membranous skin.
2. The Endosperm, a white floury mass with a firmer, darker, exterior layer just within the pericarp (this can easily be seen with a tolerably powerful lens), which is known as the **aleurone layer.**
3. The Embryo. In the embryo make out—
   (*a*) The **Scutellum,** or plate-like structure which lies on the endosperm, and serves as the means by which, on germination, the embryo is able to feed on the endosperm.
   (*b*) The **plumule,** enclosed in a sheathing leaf [by some people regarded as the cotyledon, others hold that the scutellum represents this body].

(*c*) The **radicle** terminating in a root, which, at its apex, is covered over by the coleorhiza.

Compare with the fruit of the Wheat that of a Sedge (**Carex**), and observe that this also is albuminous, but that the embryo is inside the endosperm. Carefully note the shape of the embryo.

Examine the seed of a Lily. Observe—

1. The endosperm; it is horny or bony in the majority of plants belonging to the Lily alliance.
2. The small embryo with one cotyledon.

Examine seeds of the Common Spotted Orchis. These are very minute, and require magnifying to make out their structure satisfactorily. They can be best studied by squeezing them between two pieces of glass, in water to which a little caustic potash has been added, in order to render them less opaque.

Observe—

1. The form of the seed, and the markings on the seedcoat.
2. The fleshy embryo, minute but quite distinct, with one cotyledon.
3. The **absence** of endosperm.

Thus we have now studied four Monocotyledonous seeds, and we find that, as in the previous class, the seeds may be either albuminous or exalbuminous (Orchids).

Germination of Seeds.—Sow some Garden Peas in damp sawdust, putting a few in the sawdust (which is cleaner than earth and more easily washed off the young plants) each day for a week. At the end of this time, if they have been kept warm, they will be ready for examination, and all the stages will be shown. If, however, heat is not available, some few more days may be required.

Examine the youngest plantlets, and observe that the testa has swollen, and that the radicle is protruding through the micropyle. In the older plantlets note that

the testa is irregularly split on one side, and that the epicotyledonary part of the plumule also issues from the side of the seed. It is curved over at the top. Specially notice that the cotyledons remain inside the testa, and that in any case they never appear above the ground, i.e., they are **Hypogeal.**

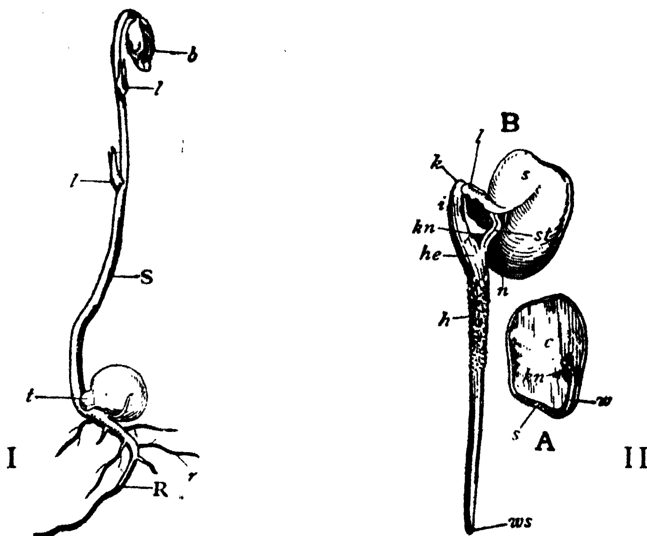


FIG. 42.—I. Garden Pea. *b*, terminal (vegetative) bud; *l*, *l*, two first leaves after the cotyledons; R, primary root; *r*, lateral root; *t*, ruptured testa. (The cotyledons are enclosed within the testa.)
II. Broad Bean. **A**, seed with one cotyledon removed; *c*, remaining cotyledon; *kn*, the plumule; *w*, the radicle; *s*, the spermoderm derived from seed-coats. **B**, germinating seed; *s*, spermoderm, a portion torn away at *l*; *n*, hilum; *st*, petiole of one of the cotyledons; *k*, curved epicotyledonary portion of axis, *i*; *he*, short hypocotyledonary portion of axis; *h*, main root; *ws*, its apex; *kn*, bud in axil of one of the cotyledons. (After Sachs.)

In still older seedlings, note—

1. That the root is elongating rapidly. Hold it up to the light, and note the dark apex and the root-cap. At some little distance behind this are the root-hairs, which are better developed if the plants have not been freely watered.

Note the lateral roots, which usually arise in four longitudinal rows on the main root.

2. That the cotyledons are still enclosed in the testa.
3. That the stem is also elongating, and first bears two very rudimentary stipulate leaves, and that, following on these, the leaves soon assume the normal adult form.

These seeds are also exalbuminous, the nourishment being stored up in the cotyledons.

Germinate some Cress seedlings by sowing them on wet sawdust or on some wet blotting-paper. The outer layer of the seed-coat will be found to swell and form a mucilaginous envelope round the rest of the seed. As germination proceeds, observe that the radicle protrudes from the micropyle, and that it soon bursts the seed-coat across the sides of the seed.

Dissect the coat off the contents of the seed at this stage, and observe how the plumule is bent sharply over, so that the cotyledons or seed-leaves lie along the radicle. Determine whether they lie with their edges or their flat surface on the radicle.

Trace the way in which the plumule becomes freed from the seed-coat.

Notice the form and manner of insertion (opposite) of the cotyledons, and that they are borne above ground **(epigeal)**, and that they become green. Observe the **Epigeal** germination in Dolichos also.

Distinguish the radicle, the hypocotyl, and the epicotyl in the embryo.

In older seedlings note the formation of the root-hairs and lateral roots, and also carefully observe the apex of the root, and that for some distance behind it there are no root-hairs yet formed. As the seedlings grow, note that the root-hairs die off from the older parts of the root. Observe, also, the form and **arrangement** of the new foliage-leaves.

As an example of the germination of an albuminous Dicotyledon, take seedlings of Buckwheat (or those of any other plant belonging to Polygonaceae or Umbelliferae). The fruits of Buckwheat may be sown in boxes of soil, and the embryos will form seedlings in a week or two, especially if assisted by gentle heat.

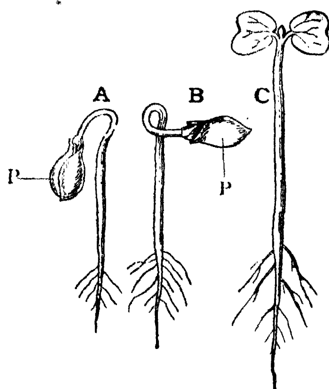


FIG. 43.—Germination of the Buckwheat (*Fagopyrum*). A, B, C, successively older stages; P, pericarp.

Note the following points:—

1. That the nut swells, and that the radicle, escaping through the thin seed-coat, bursts the pericarp at the apex of the nut, splitting it open by the angles at this spot into three flat valves.
2. The radicle penetrates the ground, and the lower part of it forms the primary root, from which lateral roots arise.
3. The hypocotyledonary part of the stem appears above ground, forming a sharp bend, at the distal end of which are the cotyledons, as yet enclosed in the nut. They are still engaged in reducing to a soluble form and absorbing, the mealy endosperm from the seed.
4. In slightly older seedlings the stem straightens itself; often, however, it does so by forming a complete revolution at the bent spot. This, however, also is commonly straightened out as the seedlings get older.
5. Finally the nut is cast off, and the cotyledons expand and become green and the plumule between them grows up, forming the main leafy shoot of the plant, as in the Cress plants.

Monocotyledons.—Allow some wheat to germinate in sawdust, and when the green shoot appears and has grown about one or two inches in length, pull some of the seedlings up for examination. [Remember that the Wheat grain is a fruit, and not a seed.]

Note that the embryo is situated at one end of the grain, and inclined towards the dorsal (not grooved) surface. Observe that the brown fruit-coat is torn by the out-growing embryo.

Carefully make out the relation of the various parts to each other, as far as can be done without dissection.

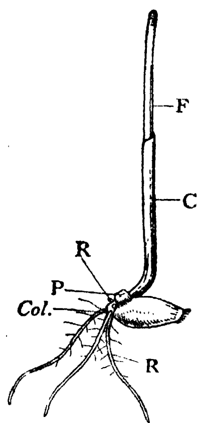


FIG. 44.—Germination of Wheat. C, cotyledon; *Col.*, coleorrhiza, with hairs; F, leaf; R, root; P, ruptured wall of fruit.

At the lower end of the embryo, note that about three roots spring irregularly from the blunt termination of the radicle. There is no primary root formed which persists to form a free-growing tap-root, as in the Pea, but the **Coleorrhiza** (covering of the end of the radicle) is bored through by the roots just mentioned. Just above them several other younger (adventitious) roots may be seen.

On the back of the embryo, just above the insertion of the roots, observe a minute scaly outgrowth **(Epiblast).** This has been by some regarded as the cotyledon.

Gently pull the embryo off the Wheat grain. Note the shield-shaped **Scutellum,** which lies, as a flattened expansion, on the endosperm. It serves to absorb the nutriment from the endosperm for the use of the rest of the embryo. [By some it is looked on as the cotyledon.]

Turn now to the plumule, and observe that the first leaf (probably this is the real cotyledon) forms a colourless sheathing organ.

Enclosed in this tube, and protruding through its apex, is the second leaf of the seedling, which soon becomes green.

In older seedlings observe how new adventitious roots arise from the first few nodes of the stem.

Compare with the process of germination in the Wheat grain that in the Barley.

Observe that the grain (fruit) is enclosed in a husk of adherent **pales**, and that the embryo bursts through these at both ends of the grain.

Note in the Barley (much more obviously than in the Wheat grain) that the coleorrhiza is furnished with root-hairs. These are especially well seen if the barley be sown on wet blotting-paper ; but they soon wither up.

When root-hairs are formed in the seedlings of these plants, observe how tenaciously they cling to particles of sawdust (or of the soil if sown in earth), so as to render it difficult or impossible to thoroughly clean them.

Other seedlings which may be compared with the Wheat are those of the Onion, in which the cotyledon is much more easily and certainly recognized, and of the Date Palm. The latter can be raised from seeds of whole dates, such as are sold in boxes, but they require a few months to germinate them successfully. Note, in the Onion, how the cotyledon is bent over as it emerges from the soil.

[The Germination of Pollen now to be described will be best studied after Chapter XV has been worked through.

The pollen of many flowers can be quite easily germinated on a slide in a weak sugar solution, and the growth of the pollen-tube followed.

Make a solution of sugar in the proportion of two parts of sugar to a hundred parts of water, and place a drop on a slide. In this sow some pollen-grains of Hyacinth (the Wild Hyacinth answers best) and put the slide under a small bell glass or a wide tumbler, containing some wet crumpled blotting-paper, in order to keep the air saturated with moisture. It is best not to put a cover-glass on the preparation till it is wanted for study, as the free supply of air is thus lessened. In a few hours the grains will

be found to have germinated freely, and to have put forth pollen-tubes. The protoplasm inside them often shows beautiful streaming motion.

Another way is to gather Crocus flowers which have had pollen placed on their stigmas the day before.

Cut off the flat stigmas as low down as possible, and let them soak for half an hour or longer in a watery solution of Iodine. Then take one of them out, and, without washing, mount it directly in glycerine. Gently squeeze it, by pressing the cover-glass, when it will be found quite easy to follow the deeply stained pollen-tubes down the less strongly coloured tissues of the stigma.

With care and patience they may be traced in the same way down the long style.

Note the **hairs** on the stigma, which cause the pollen-grains to adhere to the organ.]

PART II

INTERNAL ANATOMY AND MINUTE STRUCTURE OF PLANTS

CHAPTER XIV

GENERAL ANATOMY OF THE STEM

WE have seen that the venation of the leaf is due to the presence of vascular bundles. These traverse the petiole and pass into the stem.

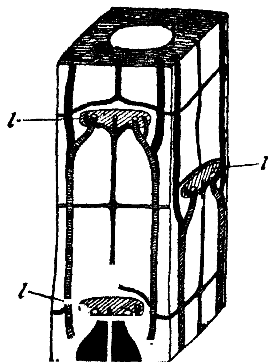


FIG. 45.—Dead Nettle, vascular system of the stem. *l*, the cut end of the leaf-stalk at the nodes, showing the five vascular bundles which enter the stem from the leaf. For description see the text.

It will be remembered that it is largely by means of the vascular bundles that substances of various kinds are distributed from one part of the plant to another. Hence, frequent unions, or **anastomoses,** between bundles occur, since in this manner the task of providing an organ with any given material is rendered easier and more certain of fulfilment if the channels are in communication with one another.

We will take as an example of the distribution of vascular bundles in the stem, the Common Dead Nettle.

Select stout specimens, and cut a piece long enough to include at least three nodes. The end nodes will then have their leaves vertically above each other, whilst the leaves of the middle node will alternate with them.

Slit the piece of stem down so as to pass **between** the end pair of leaves. You will thus, of course, divide each leaf of the middle node into two halves.

Boil the stems in water for about ten minutes, the exact time depending on the nature (succulence or the reverse) of the stem. The object of boiling is to enable you to easily dissect the soft tissue away.

When boiled, place the stems for half an hour in a solution of aniline chloride. This will colour the wood of the bundles a bright yellow.

Then pin down the half stem on to a loaded cork, and place the whole in a dish of water.

Gently dissect or scrape away the soft tissues of the stem, and make out the course of the vascular bundles in the stem.

Begin at one end, and gently work to the other.

Observe that—

Five bundles enter the stem from each leaf :—

(*a*) One thin median one.

(*b*) Two strong lateral ones.

(*c*) Two more thin lateral ones outside the last.

The outermost pair (*c*) at once unite with the strong ones (*b*) next inside them, and these compound strands run down the two corners of the stem, by the side of other strong strands which have entered from the leaves above.

The median bundle (*c*) runs down the middle of the flat side of the stem between the two strong strands. These, however, send each a branch to the middle strand, sometimes just before, sometimes just after, its entrance from the petiole into the stem.

[At the next node below, the middle strand receives another pair of branches from the strong corner bundles.]

When the next node but one is reached (i.e. that at which the leaves are directly **under** those of the first node, and not alternating with them), the middle bundle forks

right and left, and joins the strong corner strands. Be careful to make this out properly, as you may easily be led into thinking that it continues its course further down the stem. This is not the case, but as the median bundle of the leaf, at this node, enters the stem just below the forking, it may easily mislead you.

The two strong lateral bundles which have descended from above, become laterally joined to the strong lateral bundles which enter the stem from this leaf; it sometimes happens, however, that they travel down some distance further before the fusion is so complete that they can no longer be recognized as separate strands.

It is worth while to pay great attention in securing a good dissection of this stem, as, although rather intricate, it can easily be understood with care, and the exercise in manipulation will prove to be very good practice.

Other stems are less regular than that of the Dead Nettle. Thus the stems of the Balsam, Sunflower, and Dahlia may be examined as additional exercises.

CHAPTER XV

MICROSCOPIC WORK—THE CELL

General Instructions.—In examining objects under the microscope, certain points must be kept constantly in mind.

1. Have everything perfectly clean. Never allow messes to accumulate, and always freshly clean both the glass slips on which the object is to be supported and also the thin cover which is placed upon it.
2. In mounting objects for the compound microscope, they are almost always treated as transparent, and it often requires care to secure this end. They are commonly mounted in some liquid which will soak into them, such as water, glycerine, or spirit.
3. Many objects are sufficiently small to be transparent enough to mount at once, without further treatment. It is best in most cases then to mount first in water, and in some instances it may be useful to add more or less glycerine, as this reagent causes the object to appear far more transparent.
4. Very often the object to be examined is too thick and opaque to be treated in this simple way, and then we commonly take thin slices or sections of it for study. It is best then to make as thin a section as possible of the whole object, in order to get a general idea of its topography, and of the relations of its various parts. This will be studied under a low magnification (the low power of the microscope); and then for the study of details we

make very thin sections of small portions to study the character of the individual parts.

5. In cutting a section you must be very careful to know the **direction** in which the razor has passed. Three principal kinds of section are distinguished—

   (*a*) The transverse,
   (*b*) The radial,
   (*c*) The tangential ;

   and you must be very careful not to confound the two last.

The Radial section is one in which the razor passes longitudinally down the **axis** of the organ, and takes off a slice extending from the central axis of the periphery.

The tangential section is also longitudinal, but it is parallel to the tangent drawn at the periphery, and hence is at right angles to the longitudinal **radial** plane.

And in cutting these longitudinal sections it is always better (unless there is some very special reason to the contrary) to use very small bits of tissue. Thus, when you are cutting a stem, if you take a piece $\frac{1}{8}$ of an inch in length, it will usually be quite enough. It is far easier to keep your sections true and thin in these short pieces of tissue than in longer ones.

6. It is **always** necessary, in cutting sections, to keep the razor blade flooded with liquid (either water or spirit, according to circumstances), otherwise it is impossible to keep them thin without damaging them.

   It is often desirable to use various reagents or stains, in order to render special points of structure visible. But it is too often the case that these reagents, and especially stains, are abused. They should never be applied at haphazard, but always with a definite intention to secure a definite result. In fact, they should

be looked on as **tests** for the structure you wish to render more apparent.

The Cell.—In order to study a simple cell, the hairs of various plants may be taken.

One of the best examples can be obtained from the violet hairs which occur on the stamens of the Blue Tradescantia.

Take a flower-bud which is just opening, and pull out one of the stamens.

Lay it in a drop of water, and spread out the fluffy violet hairs which spring from its lower part. Cut some of these off with a sharp knife, remove the stamen, and gently put a cover-glass on the water containig the hairs. Examine with the microscope (low power), and make out—

1. The cells are arranged like a string of beads, each cell being expanded at its more equatorial part.
2. The cells are smaller towards the apex of the hair.
3. The violet colour is due to certain cell contents.

Put on the high power, and observe—

1. That each cell consists of an outer limiting **cell-wall.**
2. Closely lining this, inside, is a gelatinous skin, which is clear **(hyaline)** where it is in contact with the cell-wall and more granular within. The cell cavity is traversed by strands of this substance. This is **Protoplasm.**
3. The coloured cell-sap, which is enclosed in the protoplasm. The cavities in the protoplasm which it fills are the **Vacuoles.** Sometimes there are several of these in young cells, in the older ones they run

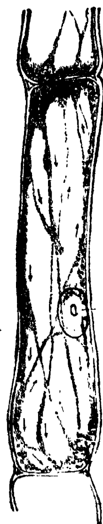


FIG. 46.—Circulation of protoplasm in an elongated cell, from a Tradescantia hair. *k*, the nucleus with a nucleolus. The arrows indicate the direction of the currents.

together to form one large vacuole, which, however, may be traversed by the protoplasmic strands already mentioned.

4. In the protoplasm a denser body can be seen, occupying various positions in different cells: this is the **Nucleus**.
5. The granules in the strands, and in the layers of protoplasm just within the hyaline layer against the cell-wall are in constant **Streaming-motion.** (This is often known as **Circulation.**) Note carefully the direction of the streaming.

Run in a watery solution of iodine under the cover slip. This is done by placing a drop of the solution against one side of the cover-glass, taking care that it does not flow over the top, and withdrawing some of the water by applying a strip of blotting-paper to the other side.

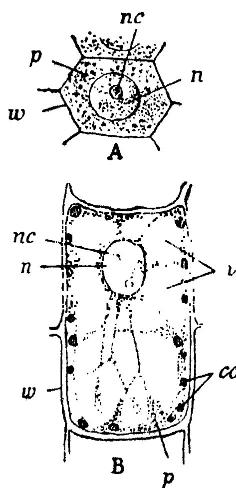


Fig. 47.—A, young cell; B, older cell. *w*, cell wall; *p*, protoplasm; *n*, nucleus; *nc*, nucleolus; *cc*, chlorophyll corpuscles; *v*, vacuoles.

Observe—

1. That movement soon ceases.
2. The protoplasm may contract from the cell wall.
3. That the protoplasm is stained yellowish brown.
4. That the nucleus is much more deeply stained.
5. That the cell-wall stains (if at all) a clear yellow.

It may happen that a Tradescantia flower cannot readily be obtaincd. A good substitute may however be found in the hairs of young tender Cucurbita stem. The cells of the hairs of the Cucurbita show all the characteristics of a fully grown mature vegetable cell. Again the isolated cells taken from the pulp of the fruit of **Zizyphus Jujuba**, are very good objects for

the study of cell structure. Fig. 47 shows two typical cells. In A the cell is young. Note that it is completely filled up with protoplasm containing the nucleus with a single nucleolus. In B, a mature cell is seen. Observe that many vacuoles have appeared and the nucleus lies connected to the cell wall by means of protoplasmic threads. The protoplasm mostly lines the cell wall and contains many chlorophyll corpuscles.

Take a piece of the white flesh from a potato, and cut sections of it with your razor.

In order to do this satisfactorily, it is necessary to flood the razor with water, in order to keep the sections from dragging or tearing on the blade. It is rather difficult to keep the water on the blade and near the edge, but practice will overcome this.

Having secured a few sections on your razor, transfer them at once to a glass slip, by laying the blade flat on it and gently guiding the sections off the blade by means of a mounted needle. You will find it easier to do this if you first lead a drop of water from the razor on to the glass.

Cover with a cover-glass, being careful not to include air bubbles, and examine with a low power of the microscope.

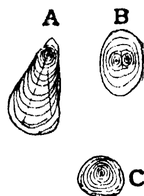


FIG. 48.—Starch grains. A and B from potato; C from wheat. (B, a compound grain formed by the common growth of two grains originally distinct.)

Observe—

1. That the section consists of numerous **cells** of polygonal outline, packed very closely together.
2. That they are filled with bright-looking bodies of variable shape and size. These are the **starch grains.**
3. The protoplasmic lining of the cell-wall, very difficult to make out.

Prepare another section, mount it in a drop of water, and gently brush out some of the starch with a wet camel's-hair brush. Cover with a cover-glass, and observe the numerous free starch grains in the water. The cells

will be easier to make out after you have thus removed some of the starch.

Run a very dilute solution of iodine under the cover glass, and observe that the starch grains turn blue. [Unless you use very dilute solutions they go blue-black immediately.]

Examine with a high power, and observe—

1. That the cells do not fit closely together all round, but that at the corners where several meet there are often **Intercellular spaces.**

   The intercellular spaces arise either by the splitting of the adjoining cell walls, when they are termed **Schizogenic,** or by the tearing or dissolution of the cells themselves when they are termed **Lysigenic** intercellular spaces. The ventilating system of the plants is formed by the schizogenic intercellular spaces. The lysigenic spaces often contain oil or other secretions.
2. The protoplasmic lining of the cell-wall, and the nucleus imbedded in it, can be seen after staining.
3. The cell-wall, which consists of **Cellulose,** will be stained pale yellow by the iodine.

Examine a starch grain in water with a high power before staining with iodine. Observe—

1. Its form—oval, but often rather irregular.
2. A spot near one end of the grain which appears darker than the rest: this is the **Hilum** of the grain.
3. Shell-like lines (of stratification) which pass round the grain.
4. Other lines running from the hilum to the periphery of the grain (striation). These are difficult to see.

Run in some very dilute potash, or sulphuric acid, and notice that the grains swell, and that the stratification becomes more distinct.

Run into another preparation some alcohol, with-

drawing all the water with blotting-paper. Observe that the stratification becomes very indistinct, and may finally disappear. The marking owes its existence to the presence of alternately watery (dark) and dense (bright) layers of substance; and any reagent which causes swelling renders the marking more obvious, whilst alcohol, by withdrawing water from the grain, makes it more difficult to discern.

Cut a section of the endosperm of Castor-Oil seed, and mount it in dilute glycerine (**Fig.** 49, *a*). Observe under the high power and note—

1. That the cells are full of oil globules.
2. That they contain a large number of proteid grains.

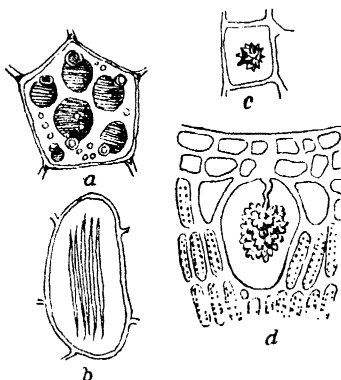


Fig. 49.—Cell contents. *a*, aleurone grains; *b*, raphides; *c*, sphaeraphides; *d*, cystolith.

Treat the proteid grains with iodine and note that they turn yellow. Note also that each proteid grain encloses within its cell a smaller round structure known as **Globoid** and a larger polygonal structure known as **Crystalloid.**

Next cut sections of Colocasia and of Opuntia (Cactus) or of Lilies. In the former note, acicular crystals (Fig. 49, *b*) known as **Raphides.** In Opuntia the crystals form spinous aggregations (Fig. 49, *c*) and are known as **Sphaeraphides.** Treat the crystals with acetic acid. This has no effect. Next try Hydrochloric acid which gradually dissolves the crystals without effervescence indicating that they are Calcium Oxalate crystals.

Calcium Carbonate crystals are found as deposits in the cell walls. Prepare a thin transverse section of a leaf of Banyan; mount in water and observe grape like mass of Calcium Carbonate known as **Cystoliths.** (Fig. 49, *d*). Put

a drop of acetic acid. The crystals dissolve with evolution of gas.

Take the common weed **Hydrilla verticillata** or **Elodea Canadensis.** The former is very common in canals, ditches, and sluggish streams, and can readily be recognized by its branching stems with whorls of small leaves of a darkish green colour.

Cut off a leaf from a plant which has been well exposed to daylight, and mount it in a drop of water. Examine it with a low magnifying power, and observe—

1. The shape of the leaf, rather oblong.
2. The midrib.
3. The cells are oblong, and contain numerous chlorophyll corpuscles.
4. The chlorophyll granules are often seen to move in a procession round the cell; they are passively conveyed, owing to the fact that the layer of protoplasm in which they are imbedded is in a state of movement round and round the cell (rotation).

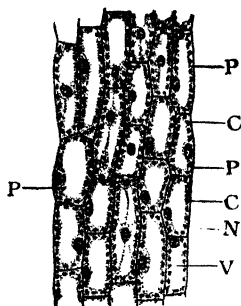


FIG. 50—*Elodea canadensis*. P, protoplasm; N, nucleus; V, vacuole; C, chlorophyll corpuscle.

Select a cell which is not too full of chlorophyll bodies, and observe—

1. Their form. Flattened disc- or oval-shaped bodies. They will be found gradually to leave the upper and lower surfaces of the cell, and to pass into the stream rotating round the side walls; they will then present their edges instead of their flattened surfaces to your view.
2. Some of them may show stages of division. These will be more or less dumbbell shaped. Finally the two ends separate, and so two

corpuscles are formed by the division of the original one.

3. The presence of starch, proved by adding iodine, which will turn the granules blue.
4. That the starch granules are formed in close connection with the chlorophyll corpuscles.

Examine a leaf which has been kept in alcohol for a few hours. Observe that the chlorophyll corpuscles, which are easily recognized, have lost their green colour.

Run in some iodine solution, and make out the different colour shown by—

1. The cell wall.
2. The protoplasm.
3. The nucleus.
4. The chlorophyll granules.
5. The starch (if present).

Observe that the cells of the leaf are not all alike, but that those of the midrib are much longer and narrower than the rest. We have here a distinction of **Tissues,** and the difference is produced by the characters of the cells composing them being different in the respective tissues.

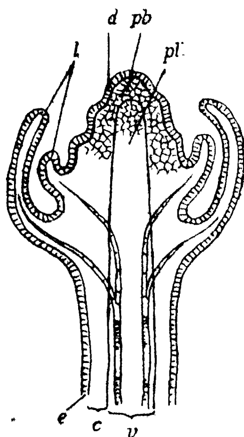


FIG. 51.—Growing point of a stem. *d*, dermatogen; *pb*, periblem; *pl*, plerome; *l*, young leaves; *e*, epidermis; *c*, cortex; *v*, vascular bundles.

In the growing regions of the cells of the vegetative cone of Phanerogams, we can distinguish three distinct tissue systems (Fig. 51). The outermost layer *d*, which covers both the vegetative cone and the developing leaves *l*, is known as **Dermatogen**; it gives rise to the cells of the epidermis *e*. The cells of the innermost tissue constitute the **Plerome,** *pl*; this gives rise to the cells of the vascular

bundles, *v*. The layer of the cells between dermatogen and plerome constitutes **Periblem**, *pb*; this gives rise to the cortex. In the growing points of roots, the outermost layer is the **Calyptrogen** which gives rise to the root-cap which has a protective function.

It is clear now that cells divide to form the tissue system. Before a cell divides into two, the nucleus first divides. The nuclei normally divide by **Mitotic** or **Indirect** division. Fig. 52 shows the resting nucleus. Fig. 53 shows the mitotic division or **Karyokinesis** diagrammatically.

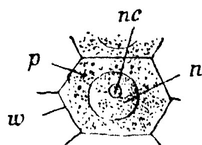


Fig. 52.

The resting nucleus consisting of delicate and diffused net work becomes coarser and gets segregated into a tangle at the commencement of the division, which later separate into short stout filaments (Fig. 53, *a*).

The filaments themselves are called **Chromosomes** and consist of regular stainable transverse discs—**Chromatin** embedded in a strand of unstainable **Linin**. The chromosomes now move and form the so called **Equitorial Plate** (Fig. 53, *b*). Each chromosome splits longitudinally, so that the number becomes doubled. The two halves of each chromosome now separate (Fig. 53, *c*) and move towards opposite directions. Those of each group unite to form two daughter nuclei (Fig. 53, *d*). Now a partition wall is formed across the cell protoplasm and the division is completed.

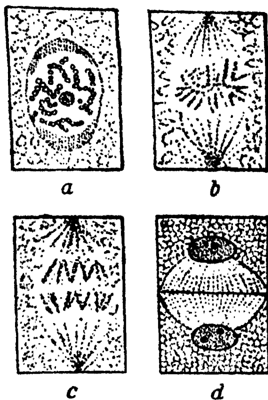


Fig. 53.—Stages in cell division. Explanation in text.

We have seen that during mitosis, the number of chromosomes at the equitorial plate is doubled. But in another kind of division, called reduction division or

Meiosis which occurs in the mother cells of the pollen grains and in spore mother cells, there is no splitting and so no doubling of chromosomes, and the daughter cells now formed receive only half the number of chromosomes. The pollen grains and spores thus contain only half **(Haploid)** the number of chromosomes of that of the plant body **(Diploid)**. The original number is restored when the union of the gametes take place.

CHAPTER XVI

STRUCTURE OF THE HERBACEOUS STEM OF A DICOTYLEDON

THE stem here selected for study is that of the Sunflower. It is easier to cut sections from a stem which has been preserved in spirit for some time than to attempt to prepare them from fresh material.

Take a young internode of the plant, and, having flooded the top of your razor with water, proceed to cut thin transverse sections of the stem. Try to cut some complete, thin, sections; others may be only partial sections, i.e. only include a small part of the stem, and you will find it much easier to cut them very thin.

When you have cut a number of sections, which will now be lying on the blade of your razor, gently place it flat on a glass slide, avoiding damaging the cutting edge, and with a needle guide all the sections which look promising on to the slide, adding water if necessary. Pick off the slip all but the best sections, and throw them away.

Run the water off the slide by gently tilting it, taking care that the sections are not washed off with it.

Add a couple of drops of weak glycerine (one part of glycerine to one part water), and be careful to see that the sections are really immersed in it.

Gently place a cover-glass over the sections. If you have added the right amount of glycerine, none will escape from the edges of the cover-glass; but if you have used too much, the excess must be carefully wiped off.

Should the glycerine get on to the upper surface of the cover-glass, it is best to take the latter off altogether, and put on a clean one in its place.

Another set of sections can be mounted in iodine water in the same way.

Another set should similarly be mounted in a solution of aniline chloride.

A further set may be cut and transferred to a slide, and the sections may then be stained with a solution of hæmatoxylin (logwood).

In order to do this, having transferred the sections to the slide, drop on them a little of the staining solution. You will have to watch them to see that they do not dry up, as the stain will shortly tend to spread over the slide. It can be turned back again by driving it with a glass rod dipped in spirit.

When the stain has been acting for about five minutes, it can be washed off with spirit, till the sections yield no more colour.

Then the sections can be mounted in glycerine as before; or they may further be mounted, after draining off the superfluous glycerine, in glycerine jelly.

[If preferred the sections, after being treated as directed immediately below, may be mounted in Canada balsam. For this purpose they must be treated, on the slide, with at least two changes of absolute alcohol, and then with a few drops of oil of cloves. They will probably tend to float on the surface of the oil. They must, however, be kept beneath the surface of the drop till they are well penetrated with the oil. This can be determined by (1) the increased transparency; (2) the cessation of diffusion currents of alcohol which will be seen at first. Then drain off the oil, drop a little Canada balsam (dissolved in benzole) on to the section, and mount with a cover-glass. Sections treated with balsam are marked by great transparency, but there is a tendency not to get them properly soaked with oil before the balsam. The sections will then have peculiarly sharp contours to the cell-walls, and, as the focus of the microscope is altered, will give the impression of moving shadows in the cell. This is always due to the above cause, and it is most frequently produced by insufficient dehydration with absolute alcohol, or this liquid has become watery by absorption of aqueous vapour from the air.]

Having secured a good **transverse** section of a young stem, observe under a low power of the microscope (Fig. 54) and make out the following points :—

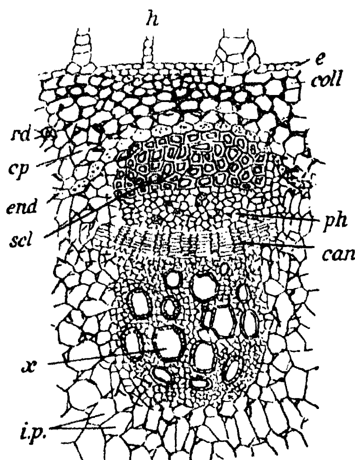


FIG. 54.—T. S. of a Sunflower stem. *h*, hair ; *e*, epidermis ; *coll*, collehcyma ; *rd*, resin duct ; *cp*, cortical parenchyma ; *end*, endodermis ; *scl*, sclrenchyma ; *ph*, phloem ; *cam*, cambium ; *x*, xylem ; *ip*, intrastellar parenchyma.

1. The outer cell-layer, which is continuous right round the section. This is the **Epidermis.** Observe that some of the cells grow out into **hairs.** [N. B. — The hairs are better seen in sections of fresh material than in that from alcohol. The latter liquid renders them brittle and easily broken off.]
2. Beneath the epidermis is the **Cortex,** composed of unequally sized parenchymatous cells. Some of the layers of the cortex lying just below the epidermis consist of cells with their walls thickened at the spot where three cells meet and the cavities appear rounded. This tissue is mechanically important to the plant, for by reason of the form of its cells, it is able to give great aid in supporting the shoot in an upright position. It is known as **Collenchyma.** Note the **intercellular spaces.** The innermost layer of the cortex is more regular, and it can be seen, on looking carefully, that the radial walls of its cells present a partially

bright appearance for the middle part of their length. This layer is known as the **Endodermis**.

3. Within the endodermis we come to the central cylinder or **Stele,** consisting of :—

   (*a*) Vascular bundles, somewhat semi-circular masses.

   (*b*) Pith, often with a great central cavity.

   (*c*) Parenchyma, uniting the pith with the cortex.

This forms the primary medullary ray. Examine one of the vascular bundles and note the following :—

1. A mass of thick walled lignified cells just within the endodermis but outside the vascular bundle. This constitutes the **Hard Bast.** Treat with iodine, the cells turn brown.

   Observe that just beneath the endodermis, all round the stem, except in the hard bast, there is a clear layer of thin walled cells, with no intercellular spaces ; this is the **Pericycle.**

2. A mass of irregular thin-walled cells, which constitute the **Phloem** or **Soft Bast.**
3. Within this comes a layer of thin-walled cells very regularly arranged—the **Cambium.**
4. Still more internally we reach the **wood,** or **Xylem.** This consists of regular rows of large thick-walled **Vessels** and **Wood Fibres** ; they have lost their protoplasm, and their walls have undergone the chemical change called **Lignification** They are separated by rows of thin-walled **Wood parenchyma.**
5. Internally, to the woody part of the bundle, are rows of small-celled parenchyma. This passes into the pith.

In the endodermis observe the absence of intercellular spaces. The cells fit together as a continuous band. Carefully note the radial walls. A small portion of each radial wall will appear darker than the rest when the whole cell is in focus. This is an optical appearance

7

due to a streak of the wall being pleated longitudinally. [It is necessary to study it in longitudinal section to see this.]

Within the endodermis we pass to the small-celled pericycle. Observe the protoplasmic contents of the cells. Nuclei may often be seen in them.

Observe the **Sieve tubes**, elements with a wide cavity (or **lumen**) and angular outline. Close to them, and obviously cut off from them, are the very small **Companion cells**, with dense contents.

The rest of the phloëm is made up of **Phloem parenchyma.**

Inside the phloëm observe the cambium cells more closely. Note the occasional formation of radial walls in them.

Within the cambium, and clearly arising by tangential division of the cells of this layer, is the wood, or xylem. Note the very regular rows of the cells of which it is composed.

Just within the cambium are thin walled cells, with cellulose walls. Some of these are small, and, if followed inwards, lead to the small-celled wood parenchyma. Others become larger as you follow the row inwards, and lead to the lignified vessels. These are, in fact, developing into vessels ; but observe that, as long as their cavities are becoming larger, their walls remain thin. Notice, also, that they contain protoplasm until they are definitely changed into their final forms. By comparing a number of developing vessels, you will conclude that they, in fact, reach their full size before their wall becomes thickened and lignified. Carefully notice the small size of the most internal (and oldest) of the fully formed vessels. These form the woody **Protoxylem** elements.

In the **Pith** observe that the more peripheral cells fit more closely together than do the inner ones. The intercellular spaces of the latter become more and more obvious towards the interior. The pith surrounds a

large cavity—really a huge intercellular space—which has arisen by the fact that the central tissues have not kept pace with the more peripheral ones, and have thus become torn asunder, leaving the cavity.

Note that in the middle of each side of the stem there is also a weaker bundle, or sometimes two or three placed close together. These bundles often have very little wood.

In the pericycle itself there may often be seen, in the neighbourhood of these small bundles, small strands of Phloëm cut transversely. These are the cut ends of small anastomosing bundles.

Take the sections mounted in iodine water, and observe that some of the cells may contain starch. Which are they? Also many cells contain protoplasm (stained brown) as a film inside the wall. In the cortex the chlorophyll granules will appear as dark-brown bodies in the cell.

Observe that the cell walls also stain different tints of yellow or brown. The tint taken on by the different tissues differing from that assumed by others.

Compare the staining produced by iodine and aniline chloride with that effected by hæmatoxylin, and carefully tabulate the results, stating the colour shown by (1) Epidermis, (2) Cortex, (3) Collenchyma, (4) Phloëm, (5) Cambium, (6) various parts of the wood, (7) Pith. [N.B.—This must be carefully done. It is not of the slightest use to stain sections at all unless you correlate the differences of colour with the differences in the tissues.]

Take, again, the sections mounted in iodine water. Irrigate the sections with fresh water, by placing a few drops at the edge of the slide and drawing through by applying blotting-paper at the other side. This is done to remove the iodine solution. Then run in a little strong sulphuric acid in the same way. [Unless the iodine solution has been washed out, dirty precipitates

will be formed on the slide.] This should be done whilst watching the section under the microscope.

Observe the following changes :—

1. The cell-walls swell up, and many of them turn **blue.** These are cells, the walls of which consist of **Cellulose.**
2. In the epidermis all the cell-walls swell up and become blue, except a thin sheet at the outside. This does not swell, nor does it become blue. It is the **Cuticle.**
3. All the cortex swells as far inwards as the endodermis, and the walls become blue. Note that the protoplasm is still brown. The walls gradually dissolve away.
4. The endodermis becomes far more distinct. The **tangential** (inner and outer) walls often swell ; while the distinct portion of the radial wall, already alluded to, does not swell. It has, in fact, been previously altered by becoming **suberized,** or converted into cork. [This is a change closely related to cuticularization.] This is insoluble in sulphuric acid, and hence becomes more distinct.
5. The cambium swells up and rapidly disappears.
6. The different elements of the wood behave differently. Those elements which retain cellulose walls (the parenchyma and **young** vessels near the cambium) become blue, swell up, and dissolve. The lignified walls of the vessels take on a stronger **brown** colour, swell up slowly, and finally also dissolve.
7. The pith cells behave like the parenchyma cells of the wood and cortex.

The lignified walls of cells also are stained yellow by aniline chloride. This reagent is then used as a test for this change (lignification) having taken place in the walls ; avoid saying that the **Xylem** stains yellow, for it is only

the **lignified** elements of xylem which are thus coloured, and moreover, as you will subsequently learn, lignified tissues may occur in tissue other than xylem.

Put a high power on the microscope, and examine again the sections (stained or unstained) mounted in glycerine (or balsam). Make out in the sections—

1. The form and structure of the epidermal cells. Note especially the **Hairs.** These are of two kinds—capitate glandular hairs, and straight-pointed ones. Note, also, their richness in protoplasmic contents.
2. In the cortex the form and character of the **Collenchyma** cells, and also the character of the **Intercellular spaces.**

   The chlorophyll granules, which can be seen in the cortical cells. Their form and appearance.

   Carefully examine the endodermal cells, and pay special attention to the radial walls.
3. The Phloëm. The large sieve-tubes and companion cells. These can be far better seen than under the low power. The phloëm parenchyma, consisting of shorter cells.
4. The Cambium. The regular arrangement and thinness of the walls.
5. The Xylem. Carefully investigate the stages in the formation of the vessels from the cambial cells. The large thin-walled elements represent these intermediate developing elements. The Wood Parenchyma. The Protoxylem, smaller vessels with rounded contours.
6. The Pith.

In transverse sections of an older stem observe that—

1. The original bundles have increased greatly in size.
2. That a layer of cells beneath the endodermis and lying between the original bundles in the

Primary Medullary rays, has divided tangentially and thus has given rise to regularly arranged thick-walled and lignified elements, the whole forming, with the xylem of the bundles, a **ring** in the stem. The new cambium between the bundles is termed **Interfascicular cambium.**

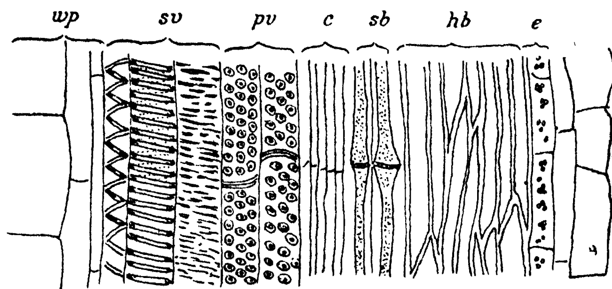


FIG. 55.—L. S of a Sunflower stem. *wp*, wood parenchyma; *sv*, spiral vessel; *pv*, pitted-vessel; *c*, cambium; *sb*, soft bast; *hb*, hard bast; *e*, endodermis.

Next prepare longitudinal sections of the stem of the Sunflower. First consider what it is you want to study. It is clear that a **radial** section is what you especially require, since this is more easily interpreted than is an oblique section. And, moreover, it is more particularly the vascular bundle which most requires elucidation. Remove the sections to a slide, and mount some in glycerine; stain others with hæmatoxylin, and then mount in glycerine; mount others in a watery solution of iodine, and others in a solution of aniline chloride.

Those stained in hæmatoxylon may be used for study, but they should be compared carefully with those which have been left unstained and mounted directly in glycerine, as well as with those mounted in iodine water and in aniline chloride.

Having placed a cover-glass over the preparations, make out the following structures under a low power:—

1. The Epidermis, with here and there long-jointed

hairs. At intervals along the section the short glandular hairs will also be seen.

2. Just below the epidermis a rather misty band of Collenchyma. This will not be seen unless the section has passed through the corner of the stem (cf. the transverse section).
3. Then several layers of short, wide cells, forming the Cortical parenchyma; the endodermis which limits this internally will scarcely be distinguished.
4. Within the last a misty layer, stained blue, which is the Phloëm, and at its inner boundary.
5. The Cambium, recognized as a thin band rather more deeply stained.
6. Within this is the Xylem, of wide elements, most of which will not be stained at all. They will be seen to possess transverse markings across many of the walls. [This part of the section will be found to be stained yellow in the aniline chloride preparation.]
7. More internally is the Protoxylem. Most of the cells take the blue stain, but various spiral markings appear on the walls.
8. Finally, the large-celled parenchymatous pith is reached.

Put on a high power ($\frac{1}{6}$ in. or over) and study the tissues in detail. Beginning at the outside, make out—

1. The Epidermis, of elongated cells. The outer wall rather thick. The cells contain protoplasm and nucleus. Note the form of the glands as seen in longitudinal section. The basal cells, which continue the epidermal covering of the stem, are much shorter than the other cells of this layer. Note the way in which the large hairs are inserted.
2. The Collenchyma. Note the thick longitudinal walls, and the thin transverse (as regards the

stem) ones. Observe that the cells contain protoplasm, nucleus, and a few chlorophyll granules. These last will have lost their green colour owing to the action of alcohol. They appear as small corpuscles in the cells.

3. The Cortical parenchyma contains chlorophyll granules in far larger quantity than the collenchyma. Observe the outer cellular spaces.
4. The Endodermis, difficult to recognize, but it often contains starch. The transverse walls are well defined, brighter and thicker than in the adjacent layers.
5. Hard bast.
6. The Phloëm. The elements of the phloëm are difficult to make out. The sieve-tubes, thin-walled elements, are recognized by their nearly transverse partitions, which stand out owing to the aggregation of slimy contents on one side of the sieve-plate. Careful study will reveal, with good illumination, the pores which traverse the sieve-plate. The parenchyma also consists of thin-walled cells, with transverse walls, which are, however, not obviously perforated.
7. Passing inward, the cambium, in which the longitudinal walls are very close together, may be recognized. Very thin sections, however, are required.
8. For xylem it is best to examine those sections which have been mounted in aniline chloride or in iodine water. Note that the walls are stained brown. [The walls of all the tissue cells will be found to be yellow or brown when stained with iodine solution.]

Passing inwards, notice the large Dotted Ducts, easily recognized by the **Pits** on the wall. Carefully study one of these pits, and note that it presents the appearance of

two concentric circles or ellipses. The border of the inner one is well defined, that of the outer one is dim. Search the section for a spot where the duct presents the cut edge of its longitudinal wall. Observe the peculiar method of thickening and be careful to make out the thin unperforated membrane, on which the thickening masses are deposited. Observe here and there that the ducts are marked by a prominent ring. This represents the edges of the perforated wall between two cells formerly distinct.

[A tube, like this dotted duct, which is the result of cell fusion of this nature, is termed a **Vessel.**]

Carefully observe that the ducts contain **no protoplasm.**

Amongst the Ducts, especially if the section is not quite radial, you will find wood parenchyma scattered. The cells composing it are rather thin-walled, and contain protoplasm.

Also you will find, in sections of old stems, other elements with thick walls and **pointed ends,** which dovetail into each other. These are the Wood-fibres, strengthening elements of the wood.

You will notice that these thickened ducts and fibres are unstained by hæmatoxylin. But examine the specimen mounted in aniline chloride, and they will be seen to be coloured yellow, showing that they are **lignified.**

Passing inwards, you reach the protoxylem. The thickening of the vessels is here very characteristic. Note the annular, spiral, and reticulate forms of thickening you will meet with. Carefully study, in the aniline chloride preparation, what parts are, and what are not, lignified.

9. Finally, you reach the pith. Make out the form of its cells, and the character of the walls.

Now take the sections mounted in iodine water, irrigate them by running in water under the cover-glass, as in the case of the transverse sections, and then run in carefully a drop or two of sulphuric acid.

Observe how the cellulose walls swell and turn blue. The cuticle of the epidermis is at once rendered visible, as it does not swell with the rest of the walls of the epidermis. The endodermis, also, can now be easily recognized.



FIG. 56.—Dead Nettle. Part of the protoplasmic contents of two adjacent sieve-tubes, after dissolving away the walls by means of sulphuric acid.

When the walls have swollen up and disappeared, carefully study the protoplasmic contents of the sieve-tubes. You can easily see that the protoplasm of one cell is connected with the protoplasm of the other by means of fine threads, which stand out sharply now the sieve-plate has been removed.

Carefully note the changes which are produced in the rest of the tissues of the stem.

If it should be found that the sieve-tubes are too difficult to make out in the Sunflower, they may be studied in the stem of the Vegetable Marrow or of the Cucumber. In these plants the sieve-tubes are of immense size. Alcohol material should be used.

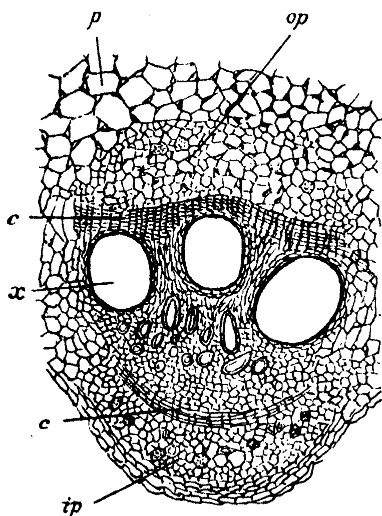


FIG. 57.—Section of Vegetable Marrow (*Cucurbita*). *p*, parenchyma; *op*, outer phloëm; *c*, cambium; *x*, xylem; *ip*, inner phloëm.

Transverse sections of the stem of one of these plants shows a somewhat different arrangement from that in the Sunflower. Thus the bundles are more numerous, and are arranged in a wavy ring.

Each bundle is furthermore peculiar in possessing a mass of phloëm on the inner, as well as on the outer, side of each xylem. Note the large polygonal cells in the phloëm. These are the sieve-tubes. Sometimes you may see the surface of a sieve-plate in these cells. The smaller cells by the side, with dark contents, are companion cells.

Cut longitudinal sections, and observe the well-marked sieve-tubes. Carefully study the plates, and note the striæ produced by the pores which traverse them. Observe that some of the plates are much thickened by the deposition of **Callus,** which stains dark brown with iodine.

Treat a section stained in iodine water in the same way as directed for the Sunflower with sulphuric acid. When the walls have become dissolved, you will have no difficulty in making out the protoplasmic connections which passed across through the sieve-plate.

Certain plants, when wounded, allow a milky juice (**Latex**) to exude from the broken parts. This juice is contained in vessels formed by the fusion of a number of originally separate cells, or in cells which are greatly elongated, and which grow out at various spots as branches between the cells of various tissues.

As an example of a plant with **Milk Vessels (Laticiferous Vessels)**, the common Sonchus or the **Plumbago zeylanica** may be taken. Any part of these plants when broken will allow the white latex to escape.

The succulent stems of the plant should be cut into lengths of several inches, and at once plunged into alcohol. This coagulates the latex, and so the tubes containing it are easily recognized in sections.

Take such a stem, preserved in alcohol, and cut off a piece about half an inch. Discard this piece, as the latex will probably have escaped from it when the plant was first cut up. Make thin transverse sections of the stem, and stain with hæmatoxylin, finally mounting in glycerine.

Note the Dicotyledonous character of the stem, the open bundles arrayed in a ring, with Interfascicular (often, however, absent) cambium. At the periphery of the cortex a beautiful collenchyma will be seen.

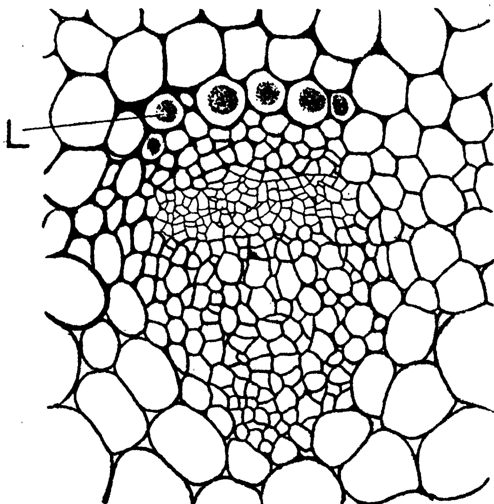


FIG. 58.—Part of the transverse section of a stem of *Sonchus* showing a vascular bundle and laticiferous vessels (L).

Immediately outside each bundle, i.e., towards the periphery of the stem, a layer of larger cells will be found to possess brown contents. This is the laticiferous tissue, and the contents are formed of coagulated latex. Observe that here and there the lateral wall between two cells may have broken down.

Cut longitudinal sections of the stem, both in the radial and the tangential direction. The laticiferous vessels may easily be recognized by their brown contents, and by the character of tubes which they present.

Look out for the evidences of their formation by the solution of part of the wall between the originally separate cells.

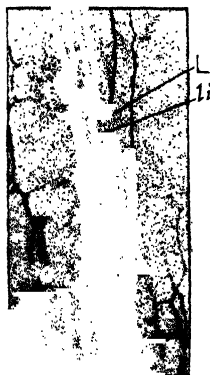


FIG. 59.—Tangential section of the stem of Sonchus passing through laticiferous vessels (L), which shows anastomoses (the lines *li* running down them indicate the walls of cells lying below the vessels).

[Turn to the transverse section and note the sclerenchyma or hard bast outside the phloëm, also the sieve-tubes and companion-cells in the latter. In the longitudinal section the sieve-tubes are specially fine. The plates are very distinct, and the continuity of the protoplasm from cell to cell in a sieve-tube row may easily be demonstrated.]

As an example of laticiferous **cells** any common spurge **(Euphorbia)** may be selected. It should be treated in the same way as the Sonchus. The laticiferous cells will be recognized in the transverse section by their coagulated contents and by their somewhat thick gelatinous-looking walls.

They are difficult to follow in longitudinal section, as they do not pursue a straight course through the stem, but take a sinuous path through the tissues.

CHAPTER XVII

STRUCTURE OF A TREE-TRUNK

[The details of wood about to be mentioned are more readily seen in **polished** specimens.]

EXAMINE the cut end of a trunk or large branch of Sisum or Mahogany, and make out the following points :—

1. The central dark-coloured heart-wood **(Duramen)** which surrounds the scarcely visible pith, or medulla.
2. The light-coloured sap-wood **(Alburnum)** which lies outside the duramen. The water from the roots travels up the stem only through the sap-wood, the heart-wood no longer serving any function, but that of mechanical support to the tree.
3. The Bark, as ordinarily understood.

Returning to the wood, notice the annual rings, and distinguish with a lens between the lighter spring wood and the denser autumn wood. [In which are vessels more frequent ?]

Next examine a similar piece of the tree which has been cut longitudinally. It is better to have both radial and tangential sections.

Observe the connection between the annual rings and the ordinary 'grain' of the stem.

Compare with the sections of the herbaceous stem those taken from a woody stem.

The apple may be selected as an example. Cut thin transverse sections of an apple twig of the current year, taking care to employ the long free-growing shoots, and not the short fruit-spurs.

Stain some of the sections with iodine and hæmatoxylin, and mount them in glycerine. Mount other sections at once (without staining) in the glycerine.

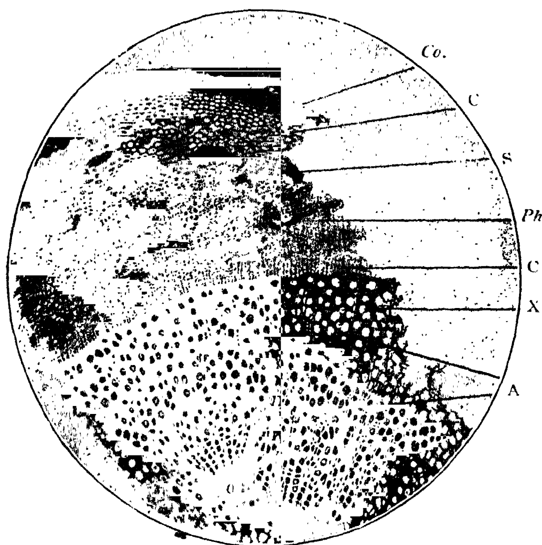


FIG. 60.—Transverse section of the stem of Apple. C, cortex; *Co*, cork; S, sclerenchyma; *Ph*, phloëm; X, xylem; A, annual rings.

Beginning from the periphery, observe—

1. The epidermis, a well-marked layer of cells containing protoplasm, the outer layers of the walls being covered by a cuticle. Here and there stomata may be seen.
2. Internally to the epidermis is a zone of collenchyma with the tangential walls greatly thickened. Intercellular spaces occur scantily in the zone. [If the material happens to be gathered in autumn or winter, a layer of cork will be found beneath the epidermis.]
3. Still more internally is a rather broad band of parenchyma with large intercellular spaces.

4. The cortex is limited internally by an ill-defined endodermis, which lies immediately outside the pericycle.
5. The pericycle, in which are differentiated isolated strands of thick-walled sclerenchyma; between these strands the pericyclic cells are of a parenchymatous form.
6. The vascular bundles, arrayed in a close ring, only separated by narrow medullary rays. In the vascular bundles observe—
   (*a*) The Phloëm, consisting of parenchyma cells, together with sieve-tubes and companion cells. The latter elements can be readily recognized, the companion-cells appearing like small corners cut off a sieve-tube.
   (*b*) The Cambium.
   (*c*) The wood or Xylem, consisting of vessels (large cavities), tracheids, and fibres of various kinds. At the inner margin of the bundle, the wood projects slightly into the pith.
7. The pith, containing intercellular spaces, the cell-walls of which are soon thickened and pitted. They finally become lignified like the wood-cells. In the autumn and winter the cells of the pith (and medullary rays) are densely packed with starch.

Examine sections taken from a stem of two or three years of age.

Again start from the outside, and observe—

1. The epidermis hardly distinguishable or absent, being functionally replaced by Cork or **Periderm.**
2. Examine the cork, and note how regularly the cells are arranged, and that the tangential walls are thickened. The cells may possess brown contents, but no protoplasm. Test a

section mounted in water by running sulphuric acid under the cover-glass, noticing how the cork resists the action of the acid. This is due to the fact that the cellulose walls have become altered [they are suberized] chemically. Observe that the inner margin of the cork is occupied by a thin-celled cork-cambium or **Phellogen,** which is rich in protoplasm.

Within the phellogen is a layer which is closely connected with it, and is the **Phelloderm.**



FIG. 61.—Apple stem. Section through (L) a lenticel (winter).

Here and there, in the cork, observe the **Lenticels** which are formed by the cork cambium, but the cells differ in—

1. Their abundance.
2. The intercellular spaces between them.

The cork layer is thus interrupted at these spots, and air is able to pass through into the interior of the stem. [If the branch be examined in winter, the lenticels, will, however, be found to be

closed within by a continuous layer of cork. This is burst open in the spring, and communication between the outer air and the intercellular spaces of the plant thus again established.]

3. In the pericycle note that the sclerenchymatous strands have become irregularly dotted about, owing to the changes which have accompanied the increase in size of the stem.
4. The phloëm has become more bulky, and its outer cells are crushed together; the medullary rays may be traced in it.
5. The cambium, similar to that in the young stem.
6. The xylem. New medullary rays are formed in this, and may be followed from the cambium inwards, where they end blindly.

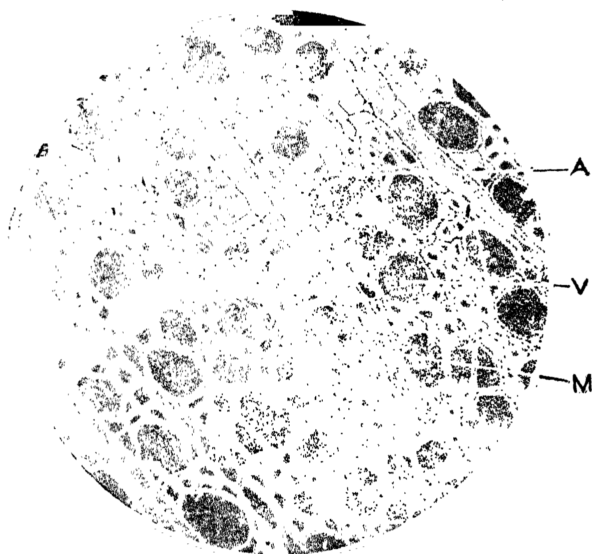


FIG. 62.—Transverse section (highly magnified) of the wood in the stem of the Apple tree. A, autumn wood of annual ring; V, vessel of the wood; M, medullary ray.

The limits of each year's growth is distinguishable on account of the denser character of the

autumn- (or late summer-) wood, and the absence from it of vessels. The dense wood is commonly three to six layers of cells in thickness.

It is to this circumstance that the appearance of annual rings is due. Study the arrangement of the wood elements under a high power, and distinguish between the vessels, fibres, and the parenchyma cells of the smaller medullary rays. Endeavour to trace the development of the wood elements from the cambium cells.

7. The pith, much as before.

Here and there you may find bundles, or groups of bundles, cut across in the cortex. These are the cut ends of bundles going to the branches.

Cut longitudinal radial, and tangential, sections, and make out the form of the various cells, comparing them carefully with the transverse sections. This is rather difficult, and needs much care to perform satisfactorily. But the medullary rays (looking like rows of bricks) can easily be seen, also the difference between the spiral vessels of the protoxylem and the dotted ducts of the later formed wood. The tracheids and wood fibres, however, will be difficult to study, and may be left, together with the cambium, phloëm, and cortex.

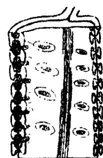


Fig. 63—Part of a duct cut down longitudinally to show the bordered pits in section and also in face view. In the upper part of the figure a transverse section of the walls is shown, and the longitudinal dark streak is seen to be due to the fact that the wall of an other vessel abuts on the one shown in the figure

Macerate some of the wood of the Apple by boiling longitudinal sections for a few minutes in Schultze's maceration solution (nitric acid, chlorate of potash, water), being careful not to carry the process too far. [The best results are obtained by allowing the sections to soak a few days in the cold liquid.]

When the tissue is softened (by solution of the middle lamella) so that the cells can easily be separated from each other, mount the sections in water, and having put on a cover-glass gently, press it to and fro till the cells come apart.

Study the form of—

1. The Vessels, elongated elements with constrictions here and there, showing where two cells have fused together. Some of these (protoxylem) may exhibit annular, spiral, or reticulated markings. These will be narrower than the larger dotted ducts, the walls of which are seen to be

crowded with **pitted** markings, which look like circular or oval spots, surrounded each by an outer and less distinct circle **(bordered pits)**.

2. The Tracheids, rather long cells with pointed ends, bearing on their walls curious markings which look like the figure I. They are really bordered pits, but the entrance to the pit has become slit-like ; the slits on the two surfaces of walls of contiguous tracheids are inclined at right angles to each other, and hence, in unseparated cells, they resemble the letter **X**.
3. Wood parenchyma-elements, the ends of which are square, and with few pits, and these not 'bordered' by an outer circle.
4. Medullary ray-cells, parenchymatous or brick-shaped, with thickened walls, which are abundantly pitted, though the pits are not bordered. They form merely holes such as might have been made by a needle. But when the cells are attached (i.e. before the solution of the middle lamella), the pit only reaches as far as this, and is not continued directly across it.

CHAPTER XVIII

GYMNOSPERM STEM

[The chief features only are insisted on here.]

THE stem of the Pine may be compared with that of the Dicotyledon. Stems of the current year should be selected, as well as those which are three or four years old.

In the transverse sections of the **young stems**, the following points should be specially noticed :—

1. The irregular contour of the section.
2. The thick-walled and strongly cuticularized epidermis.
3. The isolated groups of hypodermal sclerenchyma.
4. The large-celled tissue below the epidermis belonging to the cortex, and which passes into the main mass of the loose-celled cortex. A cork tissue arises at the periphery of the cortex during the first year's growth. A layer of cells (which?) divides tangentially twice, and thus a layer of cork cambium is formed, which gives off cork cells to the outside.
5. The large resin ducts, the cavities of which are lined by small cells rich in protoplasm.
6. The endodermis and pericycle are hardly distinguishable.
7. The vascular bundles.
8. The pith.

In the vascular bundles, observe the very **regular radial arrangement** of the elements.

(*a*) The Phloëm consists of sieve-tubes, but no companion-cells, and parenchyma. The latter can be distinguished on account of the larger cavity of the cells.

(*b*) The Cambium, thin-walled, and very regular elements.

(*c*) The Xylem, chiefly composed of tracheids, but resin ducts occur in it. Note the arrangement of these. In the tracheids look out for the **bordered pits**, which will be seen in section on the radial walls. Towards the pith the xylem elements are less regular. This region is that of the Protoxylem.

(*d*) The Medullary Rays which traverse the bundles, either run from cortex to pith (primary medullary rays) or they end on one side in the Xylem and on the outside in the Phloëm (secondary medullary rays).

In stems of more than one year's growth, note the annual rings, produced by the denser thick-walled wood cells formed in the late summer and autumn.

Notice the absence of protoplasm from all the fully formed tracheids, though it is present in the young ones which are being formed from the cambium, and of course it occurs also in the cells of the medullary rays, and in the parenchymatous cells surrounding the resin ducts.

In these older stems, observe the formation of true **bark** by the formation of new cork zones and masses deeper down in the cortex of the stem. These curve outwards, and are attached to the outermost ring of cork which is formed during the first year below the epidermis.

Cut **Radial** and **Tangential** sections of the stem. In the **radial**

sections, make out the succession of the tissues from without inwards.

Specially note the appearance of the resin passages. Also, in thin parts of the section, study the sieve-tubes. This is best done in sections stained with Hæmatoxylin. The sieve-plates are rather difficult to see; they do not occur, as in the Cucumber, on transverse walls, but on the radial walls (i.e. those which you are looking directly down on), and they appear like unstained patches, with small stained dots, lying on the walls. They are really more abundant near the ends of the cells, but in radial sections you will find it difficult to determine this, as the ends of the cells fall in the plane of the section.

In the Xylem, note the tracheids, and especially the very characteristic bordered pits, which appear as two well-marked concentric circles to each pit. The appearance of two circles is due to the facts that the inner part, or bottom, of the pit is wider than the orifice.

In the Protoxylem, spirally thickened elements can be observed. Resin passages may be seen traversing the wood in the longitudinal direction.

Carefully study the medullary rays. They are far more complex than those in the Apple stem. Note that they consist of brick-shaped cells, the long axis of the cells coinciding with the radial direction of the section of the stem. They are only a few cells wide, and the larger ones are sometimes traversed by resin passages, which thus have a **radial** course as regards the stem.

Observe the portion of a ray which is passing through the phloëm. Note that the upper and lower cell-rows have their constituent cells elongated in the **longitudinal** line of the stem: thus they come to lie along the sieve-tubes and cambial cells. This character is best seen in the inner part of the phloëm. The cells probably replace, functionally, the companion-cells which are absent in the Pine.

In the Xylem, note that similarly the upper and lower rows (often several) of this part of the ray have very thick cell-walls, in which also bordered pits occur. There is reason to suppose that they are of use in equalizing the distribution of water in the different parts of the wood.

The more central cells of the ray contain protoplasm, and in winter starch is abundant in them. This is changed in spring into sugar, and there can be no doubt but that it finds its way into the water which is rising in the tracheids, and thus provides a rapid supply of nutriment to the young twigs and leaves at this season just when they most need it.

In the **tangential** sections, the wedge-shaped ends of the cells will be seen. Also the form of the medullary rays, which look like lens-shaped masses of tissue penetrating the body of the stem.

You should endeavour to get a clear idea of the complete form of the cells of the stem by combining the results of these different aspects. The formation of a complete mental picture will be facilitated if you cut models of the cells out of a turnip or potato, and then study them in various positions. The relative positions of the cells, the distribution of the pits in the walls, and many other features, may all be clearly represented by means of such models.

CHAPTER XIX

MONOCOTYLEDONOUS STEM

TAKE one of the succulent shoots of Asparagus, cut it across, and examine the cut surface with a lens. Note that it is very different from that of the Geranium or Marigold, and that this difference is due to the scattered arrangement of the bundles. Observe that the latter are more numerous near the outside of the stem.

The Asparagus is not a very easy stem from which to obtain good sections, and it is better to take them from another monocotyledonous stem.

The Indian Corn, or Maize (**Zea Mais**), is one of the best for the purpose.

The sections are most easily prepared from stems which have been preserved for a time in alcohol. Stain some with hæmatoxylin, and mount others directly in glycerine.

Starting from the periphery of the section, the following points may easily be made out with a good hand-lens :—

1. The epidermis.
2. The interrupted bands of sclerenchyma, small-celled tissue, with thick and pitted lignified walls.
3. A mass of parenchyma, which forms the ground mass of the stem tissue. Imbedded in it are—
4. The vascular bundles, small and dense near the outside, scattered less closely and larger towards the centre.

Study one of the more centrally placed bundles under the microscope, and make out—

(*a*) The xylem, arranged like a V, with two very wide

(pitted) vessels directed outwards. The protoxylem may be distinguished, as it lies next to, or inside, the centrally placed intercellular space.

The walls of these protoxylem vessels are spiral or annular, but this can only be seen in the longitudinal section.

Between the large pitted vessels smaller lignified tracheids are arranged.

(*b*) Just outside the latter is the phloëm, consisting of very regularly arrayed sieve-tubes (the larger elements) and companion cells. Outside these is the rather crushed, horny-looking protophloëm.

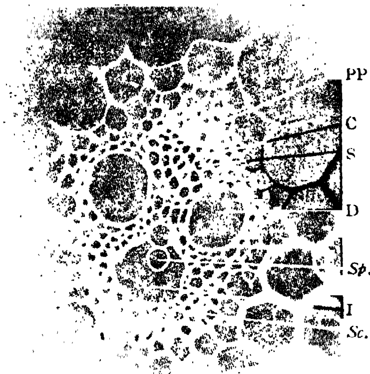


FIG. 64.—C, companion cell; S, sieve tube; PP, protophloëm; D, dotted duct; *Sp.* spiral vessel; I, intercellular space; *Sc*, sclerenchyma.

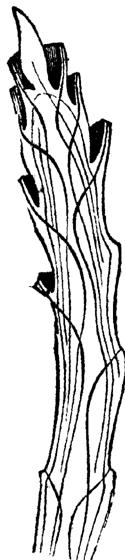


FIG. 65.—Course of the vascular bundles of *Iris* in longitudinal section (diagrammatic).

(*c*) Surrounding the whole bundle is a lignified sheath of sclerenchyma.

Specially observe that there is **no cambium** in these bundles. The reason for the scattered arrangement of the bundles in this stem can be made out by following

the bundles which enter the stem from the leaves. A large number of bundles pass in from the broad base of the leaf, and they pass in towards the middle of the stem; then, as they run down it, they will be found to curve away to the outside, finally becoming lost amidst the dense mass of other bundles in this region.

The bundles which enter the stem from the midrib part of the leaf pass farther towards the centre than do those which come in from nearer the margins of the leaves.

At each node there is a great amount of fusion between the bundles.

These points can easily be made out by boiling young parts of the stem till they are soft enough to clear away the ground tissue from the bundles.

Now cut a radial longitudinal section of a bundle of the Maize plant and make out all the points (Fig. 66).

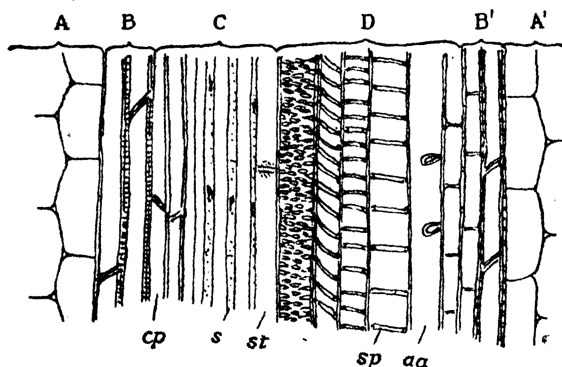


FIG. 66.—*Zea mais* (Maize)—longitudinal section. AA', parenchyma (ground tissue); BB', sclerenchyma; C, phloëm; D, xylem; *cp*, protophloëm; *s*, companion cells; *sp*, spiral tracheids; *aa*, annular ring.

[The stem of an ordinary grass, e.g. Oat or Wheat, may be compared with that of the Maize. The central part of the stem is occupied by a large air-channel, and hence the vascular bundles are not so numerous, and they are far more regularly arrayed than in the Maize, but they agree in the essential points with them.

Notice, however, the great development of the sclerenchyma, which serves to give support to the stem of these plants.]

CHAPTER XX

THE STRUCTURE OF THE LEAF.—LEAF-FALL

LEAVES of Banyan (**Ficus bengalensis**), Rubber plant (**Ficus elastica**), or the English Privet (**Ligustrum vulgare**), may furnish an example of a typical dicotyledonous leaf structure. Sections may be made of either fresh leaves, or of those which have been preserved in alcohol, the latter being easier. The leaf should be cut into narrow (⅛ inch) strips, and these laid one on the top of another, like the leaves of a book, and the whole then can be held firmly in a bit of slit elder pith or carrot. The object of having a number of strips is to increase the chance of securing that some of the sections shall be thin.

The leaf must be cut both at right angles to, and parallel with, the midrib, so two sets of strips will be required. When leaves are examined microscopically this should always be done, as the appearance presented by the two sections is often very different.

Having secured thin sections, mount some directly in glycerine and stain others with hæmatoxylin and with iodine solution before doing so.

Examine the sections under a low power, and beginning from the upper surface of the leaf, observe—

1. The **Upper epidermis.** The cells are rather irregular in form, and have thick outer walls. They form a continuous band, without any intercellular spaces. Note the absence of chlorophyll.
2. Next below the epidermis, the **Palisade parenchyma,** the cells of which are much deeper than broad. Note that several of the cells in the top layer of the palisade cells converge towards, and are attached to, single cells of the layer next

below. Note the large intercellular spaces which separate groups of the palisade cells from their neighbours. Observe the special abundance of chlorophyll in this layer.

3. The **Spongy parenchyma.** A loose tissue with large intercellular spaces. The cells are very irregular in form, and contain chlorophyll. Near the lower surface of the leaf the cells are, however, more regularly arranged.

The spongy parenchyma and the palisade layers constitute the **Mesophyll.**

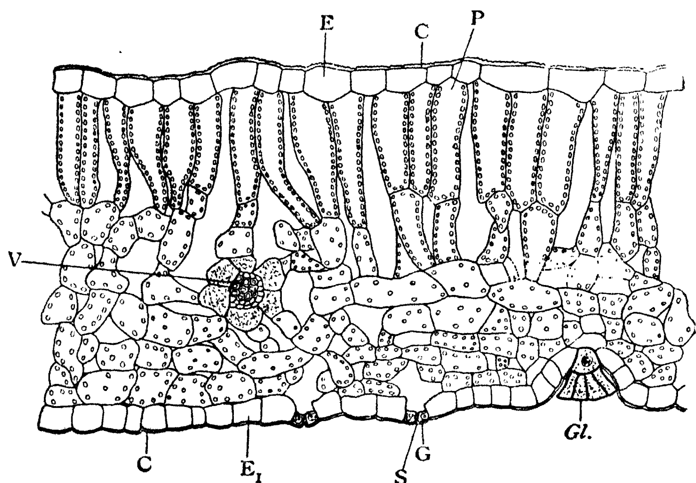


Fig. 67.—Section of a dicot leaf. E, epidermis of upper; E_1, of under surface; C, cuticle; P, palisade cells; V, vascular bundle enclosed in its sheath; S, stoma; G, guard cell; *Gl*, gland.

4. The **Vascular bundles.** Some of these will be seen cut transversely. Note in them that the xylem is directed to the **upper surface** of the leaf. Observe the sheath of rather large parenchymatous cells surrounding the bundle. Some of the vascular bundles will probably be seen in longitudinal sections also.

5. The **Lower epidermis.** The cells smaller, and their outer walls thinner than in the upper epidermis. Here and there **stomata** may be seen.

Examine stained sections with the high power, beginning at the upper epidermis. Note the following features :—

1. The outer wall of the epidermis is complex. Towards the cell cavity the wall consists of cellulose, and stains blue with hæmatoxylin. This is covered on the outside by the **cuticle,** which forms a continuous glassy layer over the whole epidermis ; this stains bright yellow with iodine, but is unstained by hæmatoxylin. The cells contain protoplasm and a nucleus. Often the epidermal cells divide, usually parallel to the surface of the leaf, here and there, giving rise locally to a two or three-layered epidermis. This is, however, not very common.
2. Study the palisade tissue more in detail, specially attending to the arrangement of the chlorophyll granules on its walls, and to its connections with the spongy parenchyma and to the vascular bundles.
3. In the lower epidermis specially study the form of the stomata. Note the shape of the **guard cells,** and the presence of a large intercellular space immediately below them. Observe also the way in which the cuticle is disposed over the guard cells. These latter cells alone of the epidermis possess chlorophyll.

Here and there depressions in the epidermis will be seen, and they are occupied by a rather large multicellular glandular hair, the cells of which are very rich in protoplasm.

Strip off the epidermis (a small portion is sufficient) from both the upper and the lower surface of the leaf, and observe the shape of the epidermal cells and the form

of the **guard cells** of the stomata. Note also the form of the glands already referred to.

Leaf-fall.—The fall of the leaves in autumn is not due merely to their withering with the cold weather, but to the formation during the summer of a 'separation layer' of cork. This cork is formed in the parenchyma at the base of the leaf (or of leaflets, when these fall off the main petiole), and a layer of the suberized tissue remains to cover the wound which would otherwise be produced when the leaf was shed.

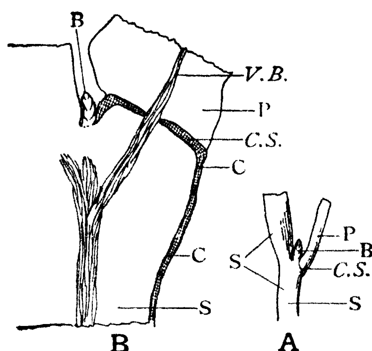


FIG. 68.—A. Longitudinal section through the stem and base of the petiole of a poplar. B. Part of the stem and petiole of A more highly magnified. S, stem; P, petiole; *V.B*, vascular bundle; C, cork tissue; *C.S.* 'separation layer'; B, axillary bud.

Poplar or Horse-chestnut shoots afford good material for the investigation of the separation layer, poplar twigs taken during the late summer being specially easy to manipulate. A short bit of stem bearing a leaf should be taken, and the blade and upper part of the petiole of the leaf may be cut away, to render manipulation easier.

Then longitudinal sections should be made through the twig and petiole, the section including the base of the leaf. The median sections will be the most instructive. They need not be very thin.

Mount in glycerine to which a little potash has been added (this will have the effect of clearing up the section

if it is not too thick), and note the band of cork which has formed across the base of the leaf. Observe that all the tissues except the lifeless cells in the vascular bundle (tracheids, etc.) are affected. The woody parts of the bundle form the projecting spots in the leaf-scar.

Very often parts of Beech or Oak plants do not throw off their withered leaves. This is especially the case with 'coppiced' (i.e. plants which have been cut down and have sprouted again from the stools) plants; the cork-layer will be found to be imperfectly formed in them, probably owing to nutritional disturbances. When it occurs on trees, it is almost always on the shaded branches of badly grown specimens.

CHAPTER XXI

STRUCTURE OF THE ROOT

Dicotyledons.—As the first example of a dicotyledonous root, we will take gram (**Cicer arietinum**).

Choose tolerably well-grown roots, also some of the thickest and oldest you can find. First cut transverse sections of the medium-sized roots at a short distance from the end connected with the plant, mount some in water, stain others in iodine, and others with hæmatoxylin.

Sections may be taken either from fresh roots or from material preserved in alcohol. Starting from the periphery, observe—

1. The Piliferous layer, a band of rather small cells. These, in many plants, grow out to form root-hairs, but in many aquatic or semi-aquatic plants root-hairs are not formed, and they will not be seen in the Buttercup root.
2. Beneath this is the bulky Cortex. The radial walls of the outermost layer of cells are **cuticularized**, and stand out sharply from the rest. This layer is termed the **Exodermis.** The cells of the cortical layers beneath the exodermis are less regular in form, usually contain large quantities of starch (blue or blue-black with iodine). The endodermis (a band of small cells) forms the innermost layer of the cortex. It is easily identified by the markings on the radial walls which resemble those on the exodermis. In older roots these walls may even be thickened and lignified.

3. The Pericycle. A continuous band just within the endodermis ; the cells are somewhat larger than those of the latter layer.
4. The Vascular strand. The xylem and phloëm groups are arranged very differently from those of the stem, the masses of xylem alternating with the phloëm. Also observe that

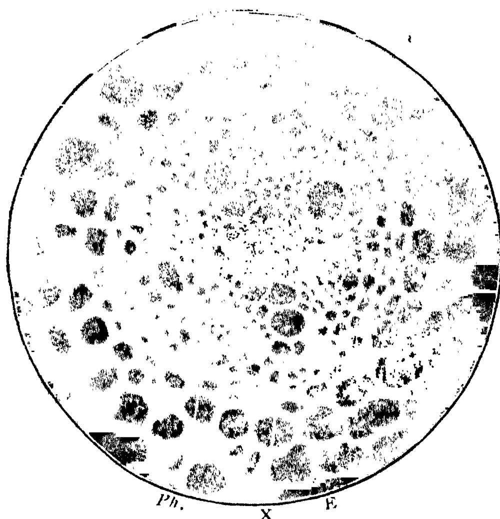


FIG. 69.—Transverse section of the centre of the root of Gram (*Cicer Arietinum*) showing four bundles of xylem (X) and four of phloëm (*Ph.*), the large xylem elements at the centre not yet lignified ; E, endodermis.

the protoxylem elements are situated nearest the **periphery,** instead of nearest the centre as in a stem.

Note the number of the alternating bands of Xylem and Phloëm. They are commonly **four** in this root, which is thus said to be **Tetrarch.**

Specially note the development of the wood. The small vessels of the protoxylem pass gradually into larger ones nearer the centre. The latter can be traced

in various stages of development by taking sections at different levels in the root.

(*a*) Near the tip only the protoxylem will be lignified, the centre of the root being occupied by elements with cellulose walls.

(*b*) Farther back some of the last-named elements will be seen to be increasing greatly in size, still preserving thin cellulose walls.

(*c*) Finally these last elements lignify, and the wood then appears as a cruciform structure.

The Phloëm is not easy to separate into its various tissues (sieve-tubes and parenchyma). Note in the older roots that in the parenchyma of the **inner side of the phloem** some of the cells are dividing, so as to give rise to a **cambium.** This tissue does not, however, in this root assume any importance, although in those of most other Dicotyledons it plays a very important part.

Cut a transverse section through a root at the place whence a **lateral rootlet** is springing (see Fig. 71). It is best to choose a part where the lateral root only just projects beyond the mother-root. Note how it has arisen deeply down in the mother-root, and has forced its way out by bursting apart (and in part dissolving) the cells which stood in its way.

Study the base of the rootlet, and you will see, by the continuity of the cells, that it has arisen from the **pericycle.** It is, however, difficult to prove this unless you have cut a very young rootlet.

Observe its position, opposite to a protoxylem mass, and also that the spirally marked vessels of the daughter-root are directly attached on to the protoxylem mass of the mother-root.

If the sections have passed through the **apex** of the young root, observe the **stratified** arrangement of the cells at the apex. Study the root-cap, and note that the peripheral cells are older than those more internal to it.

and that they are replenished from within as they are sloughed off externally.

If the rootlet be still inside the cortex of the mother-root, it will be seen to be provided with an **additional** cap, derived from the endodermis of the parent-root. This is, however, only a transitory structure, used as an aid to dissolve the tissues in front of the rootlet, and must not be confounded with the real root-cap, which is derived exclusively from the rootlet itself.

As another example of a root, we will take the root of a seedling Mustard plant (Fig. 70). For this purpose mustard seed may be sown in damp sawdust, or upon damp flannel, and when the root has attained a length of two or three inches it may be used. This will be in about a week after sowing.

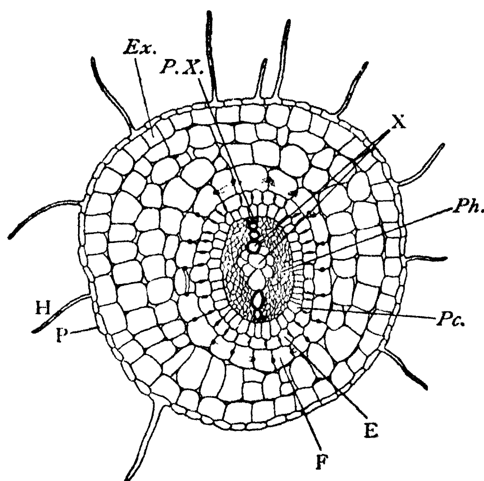


Fig. 70.—Root of Mustard. P, piliferous layer; H, root-hair; *Ex*, exodermis; F, fibrous layer just outside the endodermis; E, endodermis; *Pc*, pericycle; *Ph*, phloëm; X, xylem; *P.X.*, protoxylem.

Note the **root-hairs** on the root. The sections should be taken in the region of the hairs between one and two inches behind the growing apex.

It is better to use material which has been preserved in spirit than to cut fresh plants, as their roots are too

soft to be easily manipulated. Having secured thin sections, stain some with hæmatoxylin, and mount others in iodine water, and some more in glycerine.

Starting from the outside, note in order the following tissues :—

1. The Piliferous layer, rather irregular, one layer of cells in thickness. Many of the cells grow out into tubular prolongations—the root-hairs. Note the presence of protoplasm in these cells.
2. The Cortex. The outer cell layer **(Exodermis)** of the cortex is very well defined, and in older parts of the root, from which the piliferous layer has withered away and been lost, it forms the outer covering of the root. Then come a few regular layers of large cells with intercellular spaces. Within this is a well-marked layer resembling an endodermis. The radial walls show a thickened dot, due to the deposition of a narrow band of lignified substance around the wall of the cell. This is very common in the Cruciferæ, to which the Mustard belongs, although it is very often absent from the roots of other plants.

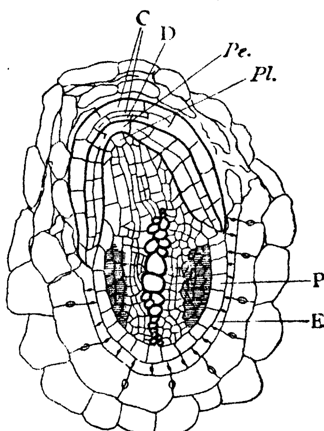


FIG. 71.—Formation of lateral root in the main root of a Cress Seedling. Only the vascular strand and inner cortical layers of the latter are shown. E, endodermis of mother root; P, pericycle; *Pl*, plerome of lateral root; *Pe*, periblem of lateral root; D, dermatogen of lateral root; the first root cap layers (C) are visible.

Within this fibrously thickened layer is the real Endodermis, of smaller cells, with a faintly visible 'dark dot' on the radial walls.

Run a little sulphuric acid under the cover-glass in order to render this endodermis more distinct.

3. Within the endodermis lies the Pericycle, a layer of cells which show irregular division here and there. This layer is important, as from it the lateral roots take their origin.
4. The Vascular strand, consisting of wood and bast. Observe the wood consists of—
   (*a*) Protoxylem, elements with small cavities lying **peripherally,** just inside the pericycle.
   (*b*) The later-formed wood, which is nearer the middle of the root [compare this arrangement with that of the stem]. Eventually the two wood masses meet in the middle.
   (*c*) The bast or Phloëm, forming, together with parenchyma, **two masses** which alternate with the **two masses of Xylem**; hence the root is called **Diarch.**
   (*d*) In slightly older roots an indication of a cambium will be seen in the parenchyma, on the inner border of the phloëm. This gives rise to new phloëm on the outside, and new xylem towards the inside. Ultimately the cambium extends across the pericycle at the ends of the xylem, and henceforward the thickening of the root resembles that of a stem. Care should be taken, by making sections at different parts of the roots, to fully understand how the cambium is first formed, and how it finally comes to assume the form of a complete ring in the root.

In some of the sections you may find that **lateral roots** have been cut. These appear as bands of tissues which

pass from the pericycle to the outside of the root, and the cells are elongated in the radial direction as regards the mother-root. In such sections make out specially the following points (which are best followed in preparations cut from parts just behind the root-hair region of the main root).

1. The lateral root arises **nearly** opposite to one of the protoxylem groups, but it is a little to one side of it.

[This position is characteristic of roots with **two** masses of protoxylems, i.e. of diarch roots ; in others with a larger number of protoxylem groups, they are usually **opposite** these protoxylems.]

2. They arise by divisions of the Pericycle at these spots, the cells of which grow, divide, and finally differentiate to form the tissues of the young root. The pericyclic cells opposite the protoxylem are often larger and richer in protoplasm than those of the rest of this layer.

The older roots of many plants undergo great changes due to secondary thickening. Ultimately they may closely resemble a stem, but if the position and development of the protoxylem can be made out, there is no difficulty in their identification.

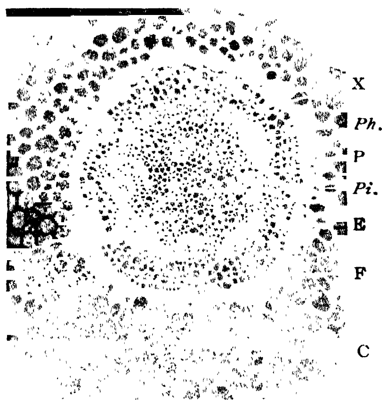


FIG. 72.—Transverse section of the young root of the Apple. E, endodermis ; F, layer just outside the endodermis, the cells of which show fibrous thickening ; P., pericycle ; *Ph.*, phloëm ; X, xylem ; *Pi.*, pith ; C, cortical parenchyma.

As an example of such a root the Apple may be taken. The roots should be dug up and carefully washed free from soil. They are much easier to cut after being kept for a time in spirit.

It is not always easy to procure good material, and the roots of the same plant often differ in some respects from one another. The thickness of a root is often but a poor indication of its age, the best criterion being distance from the growing apex in well-developed roots.

Select, first, a well-grown young root, and cut transverse sections about one or two inches (the exact distance will vary according to the character of the root) behind the apex.

Starting from the outside, notice—

1. The piliferous layer, some of the cells of which grow out into tubular root-hairs. These are almost certain to be damaged in getting rid of the soil.
2. The broad band of cortex. The outermost layer (exodermis) lies just within the piliferous layer, and as this latter is sloughed off, the exodermis remains as the external limiting layer of the root. The cortex, as a whole, contains a large amount of intercellular spaces. Passing inwards, you will find a very well-marked band of cells, with a peculiar thickening of the radial walls rather resembling a bead. This is the layer just outside the real endodermis, for which you might at first mistake it. Several groups of plants (e.g. Cruciferæ) are noticeable for this peculiarity, though it is absent from the roots of the great majority of plants. The endodermis may be recognized as the layer within this; its cells are characterized by brown contents.
3. The radially disposed groups of xylem and phloëm. There are usually five such groups, so the root is pentarch, but other numbers also occur. Note, again, the peripheral position of the protoxylem and the development of the later-formed wood-elements towards the pith,

4. The large central pith.

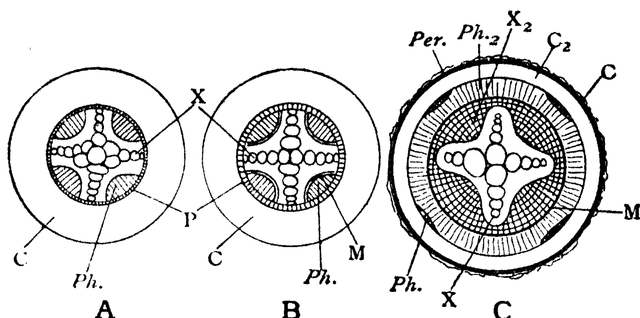


FIG. 73.—Diagram of secondary thickening in a root. **A**, before; **B**, at the commencement of: **C**, more advanced secondary thickening. C, primary cortex; P, peri-cycle; *Ph.*, primary phloëm; X, primary xylem; M, cambium; C_2, secondary cortex (derived from cork cambium); *Per.*, periderm; Ph_2, secondary phloëm; X_2, secondary xylem.

In older roots observe that a cambium has formed on the inside of the phloëm, and that it is dividing to form wood on the inside and fresh phloëm on the outside. When this has gone on for some time, the level of the newly formed wood reaches that of the protoxylem, and the cambium finally forms across **outside** these protoxylem patches. Henceforth the secondary growth quite resembles that of the stem.

Note that in the pericycle **a fresh cambium** has been formed, by its cells proceeding to divide. This cambium (cork cambium or **phellogen**) gives off cork externally and parenchyma internally.

Observe that when the ring of cork is completed that the cortex of the root shrivels, and is readily detached. The cork then becomes the external protective layer of the root, whilst the cortical parenchyma is functionally replaced by that which is formed internally by the cork cambium.

Note in this new tissue, formed peripherally to the phloëm by the agency of the phellogen, the presence of isolated cells with thick lignified walls. These are 'stone-cells,' or **stereoblasts.**

Examine the younger parts of the root, and look out for the small projections indicating the presence of young lateral roots.

Cut sections (longitudinal ones are better, but transverse ones are easier and will do nearly as well) through the root at these places. All the sections should be kept, and probably about six will be required. Pick out those which have gone through the longitudinal axis of the young root (i.e. medianly and longitudinally), and observe that it arises deep within the tissues. Trace the relation of the endodermis. This will be seen to be expanded, and finally ruptured by the young root, whereas the outermost layer of the pericycle is continuous with its external cell-layer. Thus you will conclude that the rootlet has been formed from the pericycle.

Note its position—just **opposite a ray of the protoxylem** of the mother-root (cf. the Mustard root). Examine its apex, and observe the root-cap which covers it, and which is formed by the abundant tangential divisions of the superficial cells **(dermatogen)** of the dividing (or merismatic) tissue of the growing point within the root-cap.

The root-cap is most readily studied in sections of lateral-roots thus prepared, but it is better to use rootlets which have **just** emerged from the mother-roots, as in many plants the endodermis and even outer layers of the cortex sometimes help to form a temporary covering for the very young root whilst it burrows through the cortex, and may easily be confounded with the real root-cap, with which they have really nothing to do ; for it is always derived from the division of the meristem of the rootlet itself, and not from an outside source.

Monocotyledonous Root.—The roots of young plants of Indian Corn, or Maize **(Zea mais)**, may be selected for study.

Take sections in the region of the root-hairs, also in the older parts of the root. Stain some of the sections in hæmatoxylin before mounting them in glycerine.

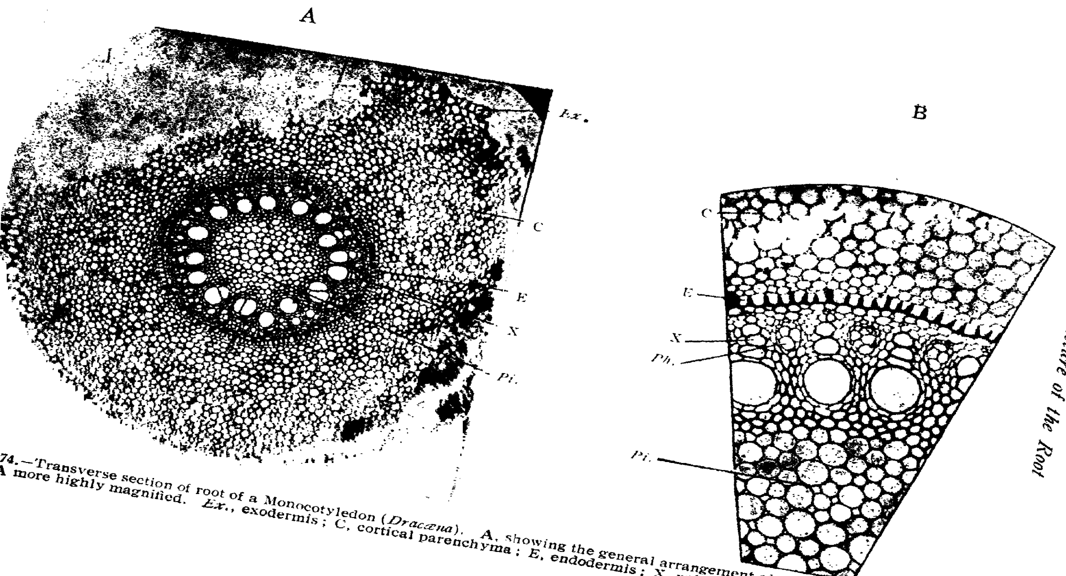


FIG. 74.—Transverse section of root of a Monocotyledon (*Dracæna*). A, showing the general arrangement of the tissues; B, part of A more highly magnified. *Ex.*, exodermis; C, cortical parenchyma; E, endodermis; X, xylem; *Ph.*, phloëm; *Pi.*, pith.

Starting at the periphery, observe—

1. The Piliferous layer. A band of cells, many of which grow out to form root-hairs.
2. The Cortex, consisting as before of exodermis, parenchymatous layers, and endodermis.

   In older roots, the inner and the radial walls of the endodermis become thickened and lignified.
3. The Pericycle, which is interrupted by the numerous xylem rays of the vascular strand.
4. The Vascular Tissue, consisting of numerous alternating masses of xylem and phloëm.

   Each xylem ray consists of a few small protoxylem elements placed peripherally and just beneath the endodermis; towards the centre of the root the vessels become very wide. The phloëm is best recognized in the stained sections. There is never any cambium formed in parenchyma on the inner side of the phloëm in the roots of monocotyledons, and hence there is no secondary thickening of these roots.

[Certain arboreous and shrubby monocotyledons (e.g. old roots of **Dracæna**) show a secondary thickening in their roots, but they do not conform in this to the Dicotyledonous type, as the secondary tissues are formed quite differently.]

5. The central Pith, very large in this case.

Compare with the root of the Maize that of the Hyacinth or Onion. Note that there are only a few xylem or phloëm masses, the roots being usually diarch. But as in the Maize, no cambium, and consequently no secondary thickening, will be found.

PART III

PHYSIOLOGY OF PLANTS

CHAPTER XXII

GROWTH IN LENGTH OF STEMS AND ROOTS AND EXTERNAL INFLUENCES ON GROWTH

Measurement of Growth in Length of Stems.—Any rapidly growing stem may be used to measure the rate of growth in length of the shoot; young Sunflower stems give good results. Mark on the stems transverse lines in Indian ink, which should be drawn about $\frac{1}{8}$ or $\frac{1}{4}$ inch apart. At least three inches of the apical end of the stem should be so marked in the case of a sunflower.

Observations should be taken from time to time, and the growth in length of the marked portion will be indicated by the increased distance separating the lines. Carefully observe that not all parts are growing at the same rate, as is proved by the unequal lengthening of the different marked intervals.

Continue these observations over several days, and note that the zone of greatest elongation in a given time varies in position from day to day. Careful drawings measured to scale should be made when each observation is made, and these can be compared at the close, and they should furnish the answers to the following questions :—

1. By how much has the marked portion of the stem elongated during the duration of the observation ?

2. Is the marked part of the stem elongating equally throughout its length at one time?
3. If not, what part of it is growing the fastest? (That is, Where is the zone of most rapid elongation situated?)

The rate of growth in a plant may be very conveniently determined by means of an **Auxanometer.** The principle of all auxanometers is the same. The elongation is magnified many times by means of a lever with a long and short arm. The auxanometer, however can measure only the total elongation.

Many grasses continue to grow at the nodes, long after they have ceased to lengthen at their apex. And the part which is lengthening is situated just above a node, and is enclosed by the sheathing part of the leaf.

To prove this, take a growing stem of Wheat or Rye when about a foot high. Cut off pieces to include a node, and about three quarters of the internode above it. Carefully remove a strip of the leaf-sheath so as to uncover a longitudinal streak of the internode down nearly as far as the node. Great caution must be employed in order to avoid injuring the stem. If the sheath gapes at all, it may be prevented from doing so by winding it (not too tightly) with silk in two or three places.

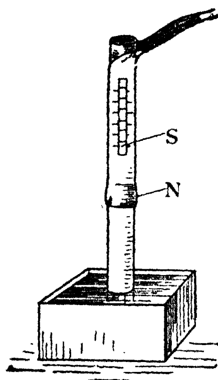


FIG. 75.—Mode of measuring growth in length of a grass stem. S, slit cut in the leaf sheath. At first the marks on the stem within the slit corresponded to those on the edges of the slit, but by growth from the node, N, this marked part of the stem has been pushed up.

Next make marks in Indian ink on the exposed streak of stem, and continue the marks on to the leaf-sheath. Place the stem node downwards in a test-tube containing some wet sand at the bottom, and close the top of the tube with cotton wool, rendered damp by previously steaming it.

Several successive nodes from the same stem should be treated in this manner. After a day or two it will easily be seen that the stem has lengthened, and is projecting farther from the open end of the sheath than before. The lines drawn on the stem will no longer correspond with those on the edges of the slit cut out of the sheath, and in this way you can determine the rate of growth in length of various parts of the stem.

This peculiarity of grasses is of great importance to them, as they are the more readily able to recover an erect position after the 'layering' produced by violent storms.



Fig. 76.—Germinating Pea held by a pin passing through the cork of the bottle. The root is marked into equal transverse zones. In the figure some of these are seen to have widened, indicating the place of maximum elongation.

Measurement of Growth in Length of Roots.—Germinate some peas, and when the radicles have reached the length of about two inches, pin the seedlings to a strip of cork and place in a jar containing some blotting-paper saturated with water to maintain a moist atmosphere. With a fine camel's-hair or sable brush, mark the root with lines separated about $\frac{1}{12}$ inch (2 mm.) apart, beginning at the root-tip, and continuing the divisions backward for about an inch.

On the following day some of the lines will be seen to have been moved apart, owing to the elongation of the root in this region.

Carefully sketch the root, and determine where the chief elongation is proceeding.

Next day again examine the specimens. Note where the elongation is going on, and observe that the part which began at first to extend has now reached its final length.

Seedlings of Scarlet-runner or of ordinary Beans will do instead of Peas for this observation. Cress is not so good, as it is apt to 'damp off.'

External Influences on Growth.—Growth is dependent upon temperature, light, supply of moisture, etc., and also on physical influences, as pressure, tension, injuries. For average plants the optimum temperature lies between 22° and 37°C. Light as a rule retards growth. Long continued darkness produces abnormal growths. If some seedlings be kept covered by a black painted bell-jar for a few days, the stems get unusually elongated and become soft and white. The leaves, instead of being green, become yellowish. Such a plant is known as an **Etiolated** plant.

CHAPTER XXIII

RESPIRATION

The Evolution of Carbon Dioxide, and the Absorption of Oxygen.— The evolution of carbon dioxide goes on during the entire life of green plants, just as animals. It is more difficult to demonstrate in the green plants, because the process of assimilation may mask it, the carbon dioxide liberated during respiration being at once seized upon for assimilating purposes.

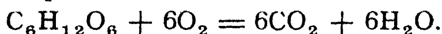
That plants, however, do respire, may be shown by taking the rapidly growing buds of trees in spring and putting a quantity of them into a large bottle, which they should about half fill. If they are put in during the late afternoon of one day, it will be found that by next morning a considerable amount of carbon dioxide has been evolved, as is proved by—

1. Thrusting a lighted match into the jar ; it will be at once extinguished.
2. Testing the gas with lime-water ; it will become milky.

If the experiment be done with germinating seeds (Barley or Bean will do), it will be found that a very large amount of carbon dioxide is produced, and an amount of oxygen, very nearly the same, has disappeared, though it requires a careful experiment to prove this.

Great deviations however occur in the germination of fatty seeds and in the respiration of certain succulent leaves. In the former case a large proportion of the carbohydrate is changed into fats, and stored as such. Consequently a less quantity of carbon dioxide is formed than the quantity of oxygen absorbed.

Respiration is essentially a process of oxidation or reduction; the end products may be represented by the following chemical formula, assuming that sugar is the substance respired. Thus—



$$C_6H_{12}O_6 + 6O_2 = 6CO_2 + 6H_2O.$$

Now the means by which the oxygen from the atmosphere obtains access to the inner tissues of the plant is mainly through the **intercellular spaces,** which form a connected series of air passages. Similarly the carbon dioxide diffuses outwards in the same way. These intercellular spaces communicate with the external air by means of the stomata or the lenticels.

These statements can readily be tested by a simple experiment, which will not only show that the intercellular spaces do form a regular aerating system, but also will enable the student to gain a good deal of information as to the conditions that affect the gaseous exchange.

If a branch, or better still the petiole, of a stout leaf be passed through a cork, so as to dip below the surface of water in a bottle, and then the air be exhausted from the space between the cork and the surface of the water, the atmospheric air will be pressed through the stomata and the intercellular spaces, and will rise in the form of bubbles through the water within the bottle.

This proves that the air can pass through the leaf, and traverse the tissues of the petiole. If the leaf be now carefully covered with vaseline on its **under** surface, to which the stomata are confined, the stream of bubbles will cease, showing that the air only passes through the stomatal lower surface. But you must be careful that the leaf is quite uninjured, as a very small lesion of its surface is quite enough to allow the air to pass into, and hence through, the leaf. You can easily show this by cutting the surface of the vaselined leaf, when the stream of bubbles will recommence.

'Anaerobic' Respiration.—Although green plants need

a continuous supply of oxygen in order to continue in a healthy condition, they are able to dispense with it for greater or less periods without dying. They continue, under these conditions, to give off carbon dioxide, although no free oxygen has access to them. Certain chemical substances in the cells are being broken up into simpler ones under the action of the living protoplasm, and carbon dioxide is one of the substances which is thus produced. But this is a very extravagant method of life, and unless oxygen be supplied the plant ultimately dies. Many seedlings, which are rich in reserve food materials, are able to live in this manner for several days, and to give off a large quantity of carbon dioxide.

In order to test this, take a test-tube about $\frac{3}{4}$ inch wide, and place in it about four or five germinating peas, the radicles of which have grown about an inch long. Fill the tube with mercury and invert it over a dish of the same metal. If neatly done, there ought to be no air at all in the tube. The peas will rise to the top of the inverted tube. Clamp the tube, so as to leave it with its open end dipping below the surface of the mercury.

By the next day, however, there should be found a quantity of gas in the tube above the peas. Leave the apparatus for another day, and note the large (relatively) increase in the volume of gas.

This gas should now be tested.

Wet a small piece of potash in water, and with a pair of forceps push it under the surface of the mercury in the dish, so that it may be allowed to rise into the inverted test-tube. It may be stopped by the layer of peas, but a little gentle movement will usually let it pass up to the surface of the mercury amongst the peas.

A better method, but one which needs care, is to force, by means of a pipette, a little strong potash solution up the test-tube, taking great care not to admit any air.

The potash will rapidly absorb the carbon dioxide, and

the mercury will again rise up in the tube, and should almost entirely fill the space left by the peas.

[Probably a small bubble will, however, be observed at the top of the tube. This consists of **nitrogen**, and its presence is due to the fact that the peas will have contained some nitrogen (derived from the air) when they were first put into the tube. As this escapes from them, it mixes with the carbon dioxide ; and since it does not combine with potash, it will be left in the form of a bubble after all the carbon dioxide has been absorbed.]

As no oxygen was admitted, it is clear that the gas (carbon dioxide) was given off by the peas.

Another test for the gas is to pass up lime-water instead of potash into the test-tube. The gas will be absorbed and the lime-water will become milky owing to the formation of carbonate of lime.

Evolution of Heat.—Allow a quantity of Peas or Barley to germinate in a pickle bottle, which may be filled for about two inches with the seeds. Through the bottle cork pass a thermometer, so that the bulb dips amongst the seeds ; place the whole in a box in a cool place. When the seeds germinate examine the thermometer, which will be found to register several degrees higher than one placed in the box but not in the bottle.

Instead of seedlings, the Inflorescences of Chrysanthemums, or flower buds of Roses in which the flowers are beginning to open, may be used.

CHAPTER XXIV

FOOD OF PLANTS

Water Culture.—In order to investigate the nature of the elements necessary for plant-life, we may employ the method known as the Water-culture method.

The essential feature of this experiment consists in growing plants in various solutions of salts, and in this way some of the requisite elements can be omitted, and the effect of such omission is apparent in the character presented by a plant subjected to these conditions.

It is clearly of the greatest importance that every vessel used should be perfectly clean, and that the salts used should be chemically pure, for without these preliminary precautions we should be neglecting factors which may ruin the results of our experiment. It is also best to have several examples of each experiment, so that if one goes wrong there may be others to fall back on.

The elements necessary for complete growth will be found to be oxygen, hydrogen, nitrogen, carbon, sulphur, phosphorus, calcium, potassium, magnesium, and a trace of iron.

Now, if we make up a solution made up of the following salts, we shall have fulfilled all the required conditions, except that we have not supplied iron or carbon. The latter element, however, is not necessarily taken in by the roots, but is absorbed from the air in the form of carbon dioxide (CO_2).

Sodium nitrate	2	parts by weight.
Calcium nitrate	2	,, ,,
Magnesium sulphate... ...	1	,, ,,
Potassium phosphate... ...	1	,, ,,
Water	2500	,, ,,

Germinate some maize or barley by letting the corns

soak in water for a day, and then keeping them on wet blotting-paper in a covered dish.

When they have grown shoots about an inch in length, the bottles can be prepared to receive them.

Bore a hole with a cork-borer in each cork, and slit the cork from the edge to the hole in order to be able to pass the plant into the latter.

We will prepare five sets of experiments, and it will be well to have at least three examples of each experiment, in case some fail.

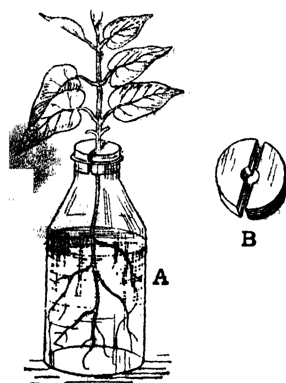


FIG. 77.—A. Method of fixing a plantlet for a water-culture. B. The cork, cut to receive the plant-stem.

Thus we shall require 15 bottles, which should hold about 10 to 20 ounces (450 cc.) each. We will label them in sets, A, B, C, D, E.

Into A and B put some of the nutritive solution, made up as directed.

Into C we will put a similar solution, from which we have omitted the **calcium** nitrate.

Into D, one from which the sodium and calcium **nitrates** have been left out.[1]

Into E, one from which the potassium **phosphate** has been left out.[2]

To the jars B, C, D, E, add a **trace** of sulphate of iron.

Now fix the plants carefully into the corks, wedging them gently with cotton wool, and place the corks in their respective jars, and put the whole lot into a well-lit place, preferably a cool greenhouse.

It is well to make paper covers for the jars in order to keep the light away from the roots. This can be done by rolling strips of paper of the requisite height into cylinders and blackening them with paint. Then they

[1] A trace of calcium may be supplied as calcium bi-carbonate.

[2] Potassium may be supplied as sulphate here.

are slipped one round each bottle. If this precaution be omitted, the plants do not thrive so well, and the water is apt to become green owing to the growth of minute organisms.

After the lapse of three weeks or a month, the different sets of plants will exhibit considerable differences amongst themselves. For a while the seedlings live on the reserve of food stored up in the seed, but, when this is consumed, they depend entirely on the constituents supplied them in the water and from the air for their further development.

Observe that the plant in A probably has its later-formed leaves of a whitish colour. This chlorotic state is due to the absence of iron, without which green chlorophyll cannot be formed. Paint the leaves with a very dilute solution of iron sulphate, and observe, after a short time, the development of a green colour.

Observe that B has grown well, and is of normal appearance, C will present a curious appearance, as if its growth had been suddenly arrested. Examine the younger leaves for starch. Boil them in water for a few minutes and then put them in alcohol to dissolve the chlorophyll. When the leaves are bleached, put them in a solution of iodine (Iodine 1 part, Pot. Iodide 2 parts, in 100 parts of water). The depth of the blue colour will show the presence of starch in each case. If starch is absent a yellowish colour only will occur.

D and E will both be very small, stunted plants but note the difference between them.

The above experiments may also be performed with Duckweed as the experimental plants instead of seedlings. The differences between the different cultures will mainly be seen in the relative degree of multiplication which they exhibit.

An instructive experiment, but one which necessitates the use of a water-bath and a good balance, is the following one:—

Weigh out two equal quantities of seed (mustard-seed works very well), say 10 grammes, and allow one set to germinate in a

moist chamber (a large pickle bottle carefully cleaned, and containing some water sufficient to keep the seeds wet, will do) **in the dark,** whilst the other set of seeds are grown under the same conditions except that they are kept **in bright daylight.**

After the two sets have been growing for a week, compare their respective growths. Probably the plants which have been kept in the dark will be larger; they certainly will be longer.

Next carefully dry all the plants of the two lots in a water-bath, the temperature of which must be kept nearly at that of boiling water. When the plants are thoroughly dry (which takes some time), weigh the two batches.

Compare the weights both with one another, and with the original weight of the seeds taken. It will be found that those grown in the dark have **lost,** while those in light have gained, in weight. The reason for these results will appear from the other experiments described in this chapter.

The drying must be done with care, and be thoroughly done, as otherwise the water will not be fully driven off, and the error thus introduced will spoil the result of the experiment.

Carbon Dioxide and Photosynthesis.—In the foregoing experiments starch was formed in the healthy plants, although we supplied no salt containing carbon. It is, therefore, probable that this element was absorbed by the plant in the form of carbon dioxide from the air.

To prove whether this is so or not, we can put two plants, each under a bell-jar which is luted in an air-tight way to a glass plate, and supply one with air deprived of carbon dioxide, whilst we do not so deprive the other of this gas.

In the first place, take two plants and keep them in the dark for a couple of days. Then test a leaf from each plant, to see that it is free from starch; if not, leave in the dark for a longer time. When the absence of starch has been ascertained, take one of the bell-jars and place inside it a saucer full of strong caustic potash solution. Then put in the plant also, taking care, of course, that it does not come into contact with the potash. Lute the bell-glass to the glass plate with vaseline or soft wax, and fill the glass tube with soda lime.

The potash solution will absorb any CO_2 that there may be in the air of the bell-jar, while the fresh air which reaches the plant through the glass tube will also

have been deprived of its CO_2 as it passes over the soda lime.

Place the other plant in the other bell-jar, but omit to put any potash inside it, and substitute pumice for the soda lime.

Place both bell-jars containing the plants under similar conditions of light and warmth, and let them have as much of the former as possible. After a couple of days (it is better to select the late afternoon of the second day) examine the leaves of the two plants for starch. Decolourize them with alcohol, which will dissolve the green chlorophyll, and then treat them with a watery solution of iodine. If the experiment has been carefully done, that grown in a CO_2 free atmosphere will show no starch, whilst a blue coloration will reveal its presence in the second one.

These experiments can also be conducted with seedlings, the roots of which dip into nutritive solutions containing very dilute solutions of a carbonate (carbonate of potash about 1 part by weight to 2000 parts of water, or half the potassium phosphate in the culture solution may be replaced by potassium carbonate). But there will be no formation of starch, or of any other carbohydrate, when the carbon dioxide is removed from the atmosphere in which the plants are growing.

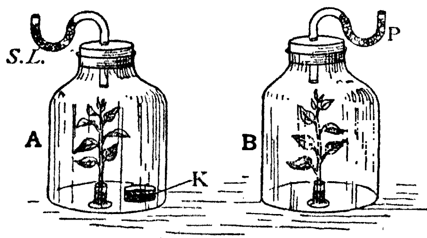


FIG. 78.—A. Bottle with tube of soda lime (*S.L.*) and glass of potash (K). B. Bottle without potash, the soda lime replaced by pumice (*P*).

If bell-glasses are not available, large pickle jars will do as well. See that they are well corked (it is well to

soak the corks in melted paraffin wax, so as to stop all holes in them), and the plants can then be placed inside them, just as in the corked bell jars. Potash is placed in one pickle bottle and is omitted from the other, and the soda, lime, and pumice-containing tubes pass through the corks as before.

Light and Photosynthesis (Carbon Assimilation).—In order to prove that the green plant can only manufacture starch when there is sufficient light, take three plants which are ascertained to have been freed of their starch by keeping them in the dark, and place one in a well-lit window, one in a part of the room fairly well illuminated, but in which it is not exposed to direct sunshine, and place the other one in a corner where the light is very subdued. Leave them in these positions for two days, and then examine them in the afternoon, taking one or two leaves off each plant, decolourizing with alcohol, and testing the leaf with iodine. Observe the difference between the three plants.

In order to show that not all the rays of which daylight is made up are equally effective in enabling the plant to form starch, the plants, freed from starch may be grown in light filtered through coloured screens. A blue and a yellow screen are the most useful.

These can easily be made as follows: Take two large wide-mouthed jars, such as confectioners use for sweets, and partly fill one of them with water in which some bichromate of potash has been dissolved. This will give an orange liquid. Now take a smaller wide-mouthed bottle, and place a little water at the bottom. Put into it the plant to be experimented with, and fit it with a well-fitting cork. Through this cork pass a glass tube, long enough to reach a short distance into the bottle, and to project a few inches outside of it. The cork should be thoroughly coated with paraffin wax on the outside when the bottle is ready for use. Then sink this bottle in the jar of bichromate of potash solution, and if the cork fits well there will be no leakage of the solution from the jar

into the bottle. The latter will have to be kept down either by means of weights or in some other way. The jar and its contents may be left in a well-lit window, or, better still, be placed in the open air.

The second jar is prepared in exactly the same way, but the blue liquid is prepared by adding ammonia to a weak solution of copper sulphate, till the precipitate which at first is formed is all redissolved.

After a day or two the plants may be examined, and that which has been grown in the orange light will be found to contain a far greater amount of starch than does the plant in blue light; indeed, probably there will be none at all in the latter.

A more convenient way of doing this experiment is to use 'double bell-jars' which are specially made for the purpose; but they are expensive. They can, however, be procured from dealers in physiological glass apparatus.

Temperature and Photosynthesis.—To prove the influence of temperature on the rate of carbon assimilation, it is most convenient to investigate water-plants, because we can more easily control the temperature of a plant in water than one in air.

Hydrilla or Potamogeton may be freed from starch by keeping the plants in the dark, and then two branches selected; one of them is put in water at the ordinary temperature of a room, whilst the vessel containing the other branch, likewise in water, is packed round with ice, which may need renewing from time to time. After exposure to bright light for a few hours, the two plants may be decolourized with alcohol and tested with iodine for starch.

Localization of Assimilation to Illuminated Cells.—In order to show that when a leaf is manufacturing starch, only those parts of the leaf which are illuminated are certainly engaged, the following experiment may be performed. Cover part of a leaf still attached to the plant with a strip of tinfoil, having previously found that there is no starch

already present in the leaves. Expose it to bright light for a day, and then cut it off, decolourize with alcohol, and on placing it in a watery solution of iodine the part previously covered by tinfoil will appear white or yellowish on a blue ground.

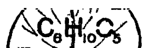




FIG. 79.—Leaf that has been partly covered with a strip of tinfoil, in which the formula for starch has been cut out. The parts exposed to light contain starch which has been rendered visible by staining the killed leaf with iodine.

If a pattern, e.g., the chemical formula for starch, be cut out of the tinfoil, it will reappear in the leaf, because starch will be formed in the part of the pattern through which light obtains access to the leaf. If the starch were not localized only in those cells which are exposed to the light (and therefore actively assimilating carbon dioxide) this sharp print would, of course, not be possible.

Conversion of Starch into Soluble Substances (Sugar).—We have often placed our experimental plants in the dark in order to get rid of the starch. This passes into the stem from the leaf, not as starch, but, after it has been **fermented,** by means of **Diastase,** to sugar. Sugar readily diffuses from cell to cell, and in this way the leaf loses its accumulated stores of carbohydrate.

Take a Fuchsia or Tropæolum which has been standing in the light, so that its leaves have become well charged with starch. Pluck some of the leaves from the plant, and place them on damp blotting-paper (to prevent withering), and put them, together with the plant, under a bell-jar in the dark. After twenty-four hours they may be examined. Compare the starch contents of the plucked leaves with those still attached to the plant.

In order to investigate the action of **Diastase,** we may either get some malt from a brewery, or, better still, grow a quantity of Barley until it sprouts. Then pick off the young plantlets from the barleycorns, and when you

have got about fifty plantlets pound them up with a very little water in a mortar.

Boil some starch, so as to turn it into a paste, and add some of this to water. As much starch as will lie on a sixpence is sufficient for half a pint of water.

Test the solution by taking a sample of it and treating with iodine. The blue colour will indicate starch.

Now to a small quantity (say a tablespoonful) add the crushed barley and water.

Again test **at once** a small sample of the mixture with iodine. After a few hours once more test a fresh sample in the same way. The iodine will probably give **no** colour, showing the starch has been changed into another substance.

The altered starch paste may be tested for sugar by boiling some of it with a little Fehling's solution, when a red precipitate will indicate the presence of **Maltose** or **Glucose**—two kinds of sugar often met with in plants. In this case, however, it will be Maltose that is present.

Dependence of Photosynthesis on the Presence of Chlorophyll.—In order to show that it is only when and where chlorophyll is present that photosynthesis and starch formation can take place, cut off a leaf of the variegated Croton (any other well-marked, variegated leaf will do as well) which has been exposed as long as possible to sunlight, steep it in alcohol to dissolve out the green colour, and then place the leaf in a watery solution of iodine. The parts of the leaf originally green will be coloured blue by the iodine, indicating the presence of starch, whilst the originally white parts of the leaf will not be so affected.

Formation of Chlorophyll Dependent on Light, Presence of Oxygen and Iron.—In order to prove that chlorophyll itself is not formed except under the influence of light, germinate some Peas, Beans, or Barley grains, keeping them all the time in darkness.

Observe their sickly yellow colour (due to **Etiolin**). Bring some of them into weak light in a room. Observe

in a short time that they begin to turn green. Note, however, that a **much stronger** light is required in order that **starch** may be formed than is needed for the development of the green colour. Place some of the rest of the seedlings at the bottom of a glass flask containing **boiled** water which has become cold (the object of the boiling is to expel the air), and then bring them into the light.

Observe that they do **not** become green. Remove them from the water into the air, and you will notice in a short time that they become green. This shows that air is necessary to the process, and we can further ascertain that it is the oxygen of the air which is the active constituent of the air.

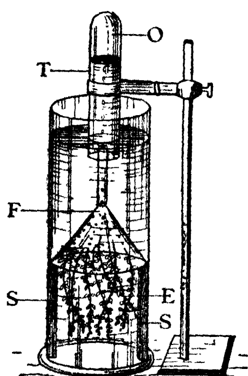


FIG. 80.—E, Elodea plants in water, with the cut ends of the stalks directed into the glass funnel, F; S, supports on which the funnel rests; T, test-tube; O, oxygen which has collected in the test-tube.

Plants grown in the dark and presenting this yellowish colour are said to be **etiolated.** [Be careful not to confuse Etiolation with **Chlorosis**, due to starvation of iron.

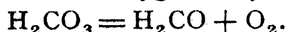
The above experiments may be repeated on Potato shoots, which are formed when the tubers are allowed to 'sprout' in a dark cellar.

Evolution of Oxygen during Photosynthesis.—A comparatively simple experiment suffices to show that during the absorption of CO_2 and the assimilation of carbon, oxygen is given off. Take a Hydrilla, Elodea or Potamogeton and cut off the branches and place these in water and leave them for some time in the sunshine. You will observe that bubbles of gas are being given off from them, especially from the cut ends.

Sink a wide glass funnel below the water over the plants so as to catch the bubbles and direct them together; allow them to flow upwards into a test-tube

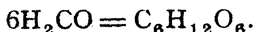
full of water, the end of which also dips below the surface of the water. As the bubbles rise the liquid is displaced, and when a sufficient quantity of gas has been collected, test it by thrusting a red-hot splinter of wood into it. The wood or match will burst into a flame, indicating the presence of a large quantity of oxygen.

The chemical action in photosynthesis leading to the evolution of Oxygen, may be represented thus :—



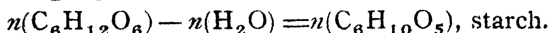
$$H_2CO_3 = H_2CO + O_2.$$

The carbonic acid gas (H_2CO_3) is formed by the union of carbon dioxide (CO_2) and water (H_2O). The aldehyde (H_2CO) formed in the process is polymerized to sugar. Thus :—



$$6H_2CO = C_6H_{12}O_6.$$

From sugar, starch grains are formed according to the following equation :—



$$n(C_6H_{12}O_6) - n(H_2O) = n(C_6H_{10}O_5), \text{ starch.}$$

The reverse process takes place when starch is hydrolyzed to sugar for translocation.

Another way of proving that plants give out oxygen when photosynthesis is active, is afforded by the following experiment.

Make a solution in water of methylene blue. This should be weak enough to be quite transparent in a wide test-tube.

Put up three tubes of the solution ; keep one, A, as a standard for colour ; into the second, B, place a branch of one of the Stoneworts **(Chara)**. Hydrilla may be used, but is not nearly so rapid. Into the third, C, place some germinating peas or barley. Put them all in the dark for twenty-four hours ; at the end of that time take them out and examine them.

A will be found to be unchanged.

B will be **decolourized** in the vicinity of the Chara (if Hydrilla be taken, forty-eight hours may be required).

C will be decolourized also.

By means of a pipette or glass tube very cautiously

withdraw some of the decolourized solution out of B and C into two test-tubes, and shake it up with air. After a time the blue colour will return, though it will be fainter than A, as some has been absorbed by the plants.

Methylene blue is a dye which readily combines with nascent hydrogen and then becomes colourless, but on shaking the decolourized solution up with free oxygen the blue colour is restored.

Place the tube B with the rest of the colourless liquid in a bright window, and observe that the blue colour returns. This is due to the oxygen liberated during photosynthesis.

The peas in C have also become stained by the dye, but probably they will not appear blue owing to the change above mentioned, which has been brought about in connection with respiration. By rinsing them in water and cutting them open, the blue colour gradually develops as the oxygen of the air obtains access to the tissues.

[It is desirable to cut a slice off the cotyledons of the pea **before** putting them in the solution of methylene blue, or the dye may not penetrate beyond the testa and radicle of the seeds.]

CHAPTER XXV

ABSORPTION, TURGESCENCE, MOVEMENT OF WATER, TRANSPIRATION

Absorption.—In submerged aquatic plants and in plants of low organization, absorption of water takes place throughout the surface of their bodies. In land plants this function is carried on by the roots and root-hairs. Cells of the root-hairs are very much elongated, and consist of a vacuolated protoplasm enclosed by a cellulose membrane. Imbibition of water first takes place by the cell walls and then water diffuses into the cells by **Osmosis.** The diffusion into the denser liquid, is termed **Endosmosis** and the reverse process is termed **Exosmosis.** The cell wall is permeable to both water and salts, but the protoplasm is not so. The lining layer of the protoplasm is only **Semi-permeable,** i.e., permeable to certain substances only. It allows **endosmosis,** i. e., the passage of water through the protoplasmic membrane, to go on freely but very little **exosmosis** of the dissolved constituents of the cell sap takes place.

The property of semi-permeability may be also demonstrated in the precipitation-membrane formed when copper sulphate solution comes in contact with potassium ferrocyanide solution.

To show the physical nature of the process of absorption of water by the root-hairs, cover a thistle funnel at the broad end by an animal membrane. Filling it up now partially with a strong sugar solution, place the broad end in a vessel containing water and note the level of the liquid within the tube. In a short time, the level in the tube rises, owing to absorption of water from the outer vessel. The **Osmotic Pressure** of the sugar solution may be found by connecting the narrow end with a mercury manometer.

Withering of Shoots and Leaves.—Take some green

leaves or shoots of any herbaceous plant, and place some in water, and leave others on the table. After a time the latter will be found to be **withered**; they lose their stiffness and become limp, whilst the others will have remained fresh.

Place the withered shoots in water, first cutting a fresh surface at the lower ends of their stems, and in a short time they will recover, and the leaves will become once more plump and stiff. Clearly, therefore, the limpness is due to the loss of water by the leaves, and their recovery and renewed stiffness to their having taken up a fresh supply of water.

The limp shoots can be very quickly restored by forcing water into the cut end of the stem. For this purpose connect the stem by means of well-fitting indiarubber tubing, with the shorter leg of a glass tube bent in the form of a J. Before doing so, fill both the indiarubber and the glass tube with water.

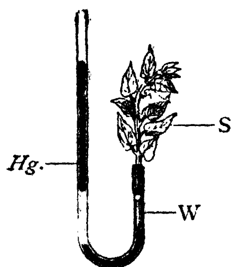


FIG. 81. – Injection of withered shoot (S) with water (W) by means of the pressure exerted by the column of mercury (*Hg.*).

Now pour mercury down the longer leg of the tube. As it rises in this leg, it will exert a greater pressure on the water in the shorter limb, and will force it into the plant.

Plasmolysis.—In order to ascertain the behaviour of the individual cells towards water, we may strip off a bit of the red epidermis from the under surface of the leaf of Saxifraga or examine the hair of the stamens of Tradescantia.

Mount in a drop of water on a glass slide, and, placing a cover glass on it, examine with the microscope. Select a part of the skin where the cells are large, and the red colour is well shown, and observe—

1. That the colourless protoplasm is in contact with the wall all over its inner surface.

2. That it contains a large central vacuole filled with red sap.

Run in a three per cent solution of salt under the cover glass, drawing off the excess of water with blotting or filter paper, held to the opposite edge of the cover-glass.

Observe—

1. That the cells become smaller (that is rather difficult to see).
2. That in a few minutes the protoplasm of many cells is partly contracting from the wall, owing to the fact that its central vacuole is losing water, and therefore ceases to distend it. Often beautiful protoplasmic filaments can be seen to extend from the contracted protoplasm to the wall of the cell.

Run in plain water once more, washing out the saline solution, and observe that the vacuoles again absorb water, the protoplasm again becomes distended and pressed up against the cell-wall.

Kill the cells by heating the water gently, and observe—

1. That the coloured sap diffuses out of the vacuole.
2. That it is impossible to render the cells turgid by adding water to them, or to extract water from them by surrounding them with saline solutions.

These observations show—

1. That the cell wall is readily permeable to water.
2. That the protoplasm is readily permeable to water, but that—
3. The living protoplasm does not allow the coloured substance, nor the substances which have an affinity for water, in its vacuole to pass through its substance.

4. That the affinity which the contents of the vacuole possess for water is weaker than that possessed by a saline solution, of the strength we have taken, for fresh water. That this is so is proved by the fact that water is lost from the vacuole, and passes out into the saline solution.
5. That these properties depend on the living condition of the protoplasm.

Cells, the protoplasm of which is shrunken owing to the withdrawal of water in this way, are said to be **plasmolysed,** whereas cells which have absorbed so much water that their walls are being stretched, are said to be **turgid.**

In an ordinary leaf which is supplied with water, the stiffness is due chiefly to the turgid condition of its cells, whilst the flaccid character of one which has been deprived of water is due to a loss of turgescence. But the cells are not called **plasmolysed** in this latter case, because the water has been lost by evaporation, and has not been withdrawn by the attraction which molecules of a salt may have for this liquid.

Plasmolysis is merely a very easy and accurate means of studying the behaviour of living cells in various states of turgescence.

Turgescence.—Take a small piece of a turgid shoot of tobacco or Chenopodium or cut a young twig of Elder, choosing one of the thick, succulent, strong-growing shoots. Cut out a length in an internode of, say, an inch. Measure its length carefully. Then remove the woody ring, leaving the central pith intact.

Observe, when you have done so, that the pith becomes **longer** than it was before. Measure the elongation. Soak the piece of pith in water for a few minutes and again measure. It will be found to have increased still more in length.

Next let the piece soak for a time in a five to seven

per cent solution of common salt. Observe and measure the **contraction.** This is due to loss of turgescence, consequent on immersion in the salt, whereby the elastic cell-walls have reduced the size of the individual cells.

Wash the pith free from salt, and let it soak again in a dish of fresh water (use rather a large dish of water, so as to weaken any of the salt solution which may have escaped the washing out); the pith will again become longer.

Boil a piece of fresh pith before trying these experiments, and observe that salt solution causes no diminution in length.

The lengthening of the piece of elder pith as a whole is due to the fact that the constituent cells are able to elongate considerably in **length.** They also enlarge in breadth.

Cut a piece of elder twig about ¼ or ½ an inch in length, and slit the outer tissues as far down as the pith, and gently free this from the wood which encloses it. Place the piece of stem in fresh water, and observe that the pith also increases in diameter, as is shown by the gaping edges of the slit.

Now immerse it in the salt solution, and after a short time you will again be able to make the lips of the slit meet round the pith.

Some structures when placed in water elongate principally in the radial direction, and this may even result in causing a shortening of the length, accompanied by an increase in the girth of the organ.

A good example of this may be seen in the root of **Carum.** Many other roots will do if these should be difficult to get, but it is best to select rather fleshy roots for the purpose.

The tap-roots are taken, and the shoot cut off from them, also any lateral roots, together with the thin apical end. The root is then fixed (with pins), stuck through the thick end into a strip of wood, and wire rings may be

wound at intervals round the wooden support so as to keep the root in one line.

A piece of wire is fastened down to the wood just alongside the root, and two marks are made on it with a file, one being close to the pins, the other near the free end of the root.

With a sable brush and Indian ink make two lines on the root close to the file marks on the wire, and when these are nearly dry, the whole may be placed beneath the surface of water in a dish.

After a while (some hours) the root will be seen to have shortened, as shown by the distance between the ink-marks being less than that between the file-marks. [It is better to use wire for the standard scale than to mark this on the wood, to avoid the chance of swelling and lengthening on the part of the sçale itself.] The root at the same time increases somewhat in girth, but this is very difficut to measure.

Now place the contracted root in salt solution, and observe the lengthening which occurs in a short time.

Older roots will plainly show evidence of the contraction by the wrinkles visible on their surface.

This peculiar behaviour of roots is due to the fact that, when turgid, the cells of the cortex elongate so much in the **radial** direction that they become shorter in the longitudinal one, and hence a turgid root becomes a good deal broader, and at the same time shorter, than the same root when flaccid.

These experiments have taught us that—

1. Individual cells, and consequently tissues also, may lose water by evaporation or by plasmolysis.
2. And when they do so they cease to be turgid.
3. And that when they cease to be turgid, the group of cells as a whole becomes limp, and that, consequently, if a succulent shoot loses more water than it obtains, its cells cease to be

turgid, and the shoot as a whole becomes flaccid, exactly as our herbaceous shoots did when left on the table to wither.

4. And just as, when the cells are put in a position to freely absorb fresh water, they become turgid and tense, so the withered shoots, immersed in water, again become stiff, because their constituent living cells are able to resume their normal turgid condition.
5. The state of turgescence of a tissue is dependent on the living condition of the individual cells which together constitute the tissue.
6. Whether elongation or contraction of the tissue or organ as a whole is the result of a state of turgor, will depend on the character of the cells composing it—that is, on the form they assume when in the turgid state.

Tensions in the Tissues.—In many stems and roots different degrees of stretching in the various tissues may be induced by rendering all the cells turgid which are capable of becoming so.

Take a young turgid shoot of Chenopodium or tobacco or take the stalk of a Dandelion head and cut off pieces about two inches long and slit into about four strips.

Place the strips in a glass of water and observe that they curl up. Notice which side is outermost (whether the epidermis or the pith). This curling indicates that the outer side of the curve has become **longer** than the inner (concave) one, and it is due to the fact that the cells on the convex side have absorbed more water and have stretched to a larger size.

Now place the curled stem in a four or five per cent solution of common salt.

Carefully note what happens. The effects are due to diminished turgescence, consequent on the withdrawal of water, by the saline solution, from the cells of the plant,

and that certain (which?) cells lose relatively more water than others.

Root-pressure and Bleeding.—In the spring of the year, just as the leaves are about to unfold, many plants, if cut down, exhibit the phenomenon of **Bleeding.** This is due to excessive absorption of water by the root, and the result is an escape of water from the cut end of the stem.

It may be shown best by cutting a Vitis or Tropæolum back to near the ground; but other plants may be substituted, though few show it in so striking a manner. Young plants of Scarlet Runner (**Phaseolus**) may be used.

Have ready—

1. A piece of glass tubing about three or four feet in length, of small bore (say ¼ inch), and attach a short piece of indiarubber tubing to its lower extremity.
2. A stand by which the tubing can be adjusted and held in position.
3. A Vitis or other climbing plant, preferably in a pot, but at any rate rooted in soil.

Cut off the shoot of the plant just below its oldest branch, wet the end with water, and attach the glass tube by means of its rubber tubing to the rooted stock.

Clamp the glass tube in position on the stand (1).

Make a series of marks with Indian ink at measured intervals on the tube, and observe that the water after a time begins to be forced into the tube by the plant. Note the rate at which the bleeding goes on.

If the Vitis be selected, the phenomenon occurs very rapidly and will soon fill the tube and overflow it.

If, however, the Kidney Bean be used the bleeding is not nearly so active, and takes much longer time to become apparent.

Next, whilst the water is still rising in the tube, cut off carefully the root from the base of the stem, and allow the latter to dip into a dish of water, whilst it is still

attached to the apparatus. No more water will be forced up the stem, but that which has already been pumped up will begin to fall, showing that the bleeding is due to **Root-pressure.**

Repeat the experiment on bleeding later on in the early summer, when the plant has made its growth of leaves. You will find that bleeding will probably not occur, indicating a greatly diminished root-pressure.

Transpiration.—To prove that plants **transpire,** or give off watery vapour, take two tumblers partly filled with water, and cover each of them with a card which has a hole bored through its centre. Pass a small leafy twig (a bit of Melia, or Lantana or any other similar plant will do) through the hole in each card so that its stem dips into the water below. Stop up the sides of the hole with wax and cover the leafy shoot with another tumbler.

Place one pair of glasses in a window, and the other one in a cool place at the back of the room. In a few minutes you will see that the upper glass of the pair in the window is bedewed with water, which has been clearly given off as vapour from the plant and has become condensed on the surface of the tumbler.

The other apparatus will require a very much longer time for the dew to appear.

This experiment proves—

1. That plants transpire, or give out watery vapour.
2. That they do so more quickly in the light than in the shade.

Stomata and Transpiration.—Take two Banyan leaves. Paint the under surface of one with vaseline and seal the cut ends of both and hang them in a room for a few days. Note that the unpainted one gets dried while the painted one remains fresh. Again if blotting-papers soaked in 5 per cent solution of cobalt chloride after drying be placed on both sides of a leaf and covered by two glass plates to prevent moisture from outside acting on the cobalt paper, the paper in contact with the under surface

soon turns pink, showing that water vapour being given off from the stomatal surface.

Measurement of Transpiration.—The preceding experiment tells you that transpiration goes on, but it does not tell you at what **rate** it is proceeding. To ascertain this you must **measure** the **amount of water** which passes from the plant in a **definite time.**

We can get at this fairly easily by measuring the amount **absorbed** in a given time

Prepare—

1. An iron stand with a clamp.
2. A leafy branch, the stem of which should be about $\frac{1}{4}$ or $\frac{3}{8}$ of an inch in thickness, and which should be cut off with its end under water and kept so till required.
3. A piece of indiarubber tubing to fit the lower end of the branch tightly; a length of $2\frac{1}{2}$ inches will be enough.
4. A piece of barometer (small bore) glass tubing, which will be fitted tightly by the indiarubber tube. The glass tube should be about eighteen inches long.
5. A dish of water.

Pass the indiarubber tube over the lower end of the branch for about an inch. **Fill the free end up with water,** and then force the glass tube into this end; the water will be forced into the barometer tube, which it must **completely** fill. Dip the end of the glass tube under the water in the dish whilst it is being forced into the indiarubber.

Now fix the plant in the clamp so that the glass tube slopes gently upwards. Leave the whole apparatus for half an hour or so, in order that the branch may become accustomed to its new conditions, and that its temperature may become the same as its surroundings.

Then gently raise the end of the glass tube out of the dish. As watery vapour is given off from the leaves,

that in the tube will be drawn up to take its place, and of course air will enter at the end. Now sink the end again below the water. As the plant continues to transpire, the water will be drawn again into the tube, but the bubble will mark the level to which the fresh supply of water has risen. Hence by taking the time which the bubble requires to pass over a certain length of tube (i.e. the time which the water has taken to rise through this same length) we can calculate the rate of transpiration if we know the area of the cross-section of

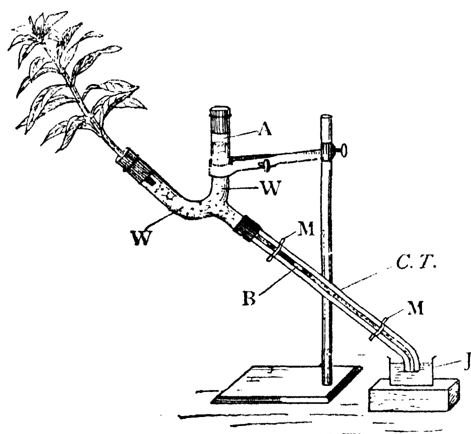


FIG. 82.—Potometer. The plant is fixed air-tight into one limb of the U tube. W, water; A, air (formed by the accumulation of bubbles); B, bubble; M M, marked intervals on the capillary tube (*C. T.*); J, jar of water into which the end of the tube dips.

the tube. Thus if the internal diameter of the tube be $\frac{1}{20}$ inch, the area of the tube will be ·002 square inch (nearly). And if we made ten inches as the distance through which we watched the bubble traverse, and it took five minutes in doing it, we should see that the plant was transpiring $\frac{\cdot 002 \times 10}{5} = \cdot 004$ cubic inch per minute, or that it would take four hours ten minutes to transpire one cubic inch.

This apparatus is known as a **Potometer,** because it measures the amount of water which the plant absorbs. It is not quite an accurate measure of the transpiration, since some of the absorbed water may be retained by the plant. This, however, forms so small a fraction of the whole as to be negligible.

[A more convenient form, but more difficult to make, is shown in Fig. 82, but it has the advantage that it can be used for a number of observations, since the air bubbles are prevented from accumulating at the cut end of the stem (and thereby reducing and ultimately stopping the transpiration) by being directed into the glass limb A.

Thus the effects of varying temperature and light can be studied on the **same** specimen, but in this case care must be taken that after each **change** of conditions the plant has conformed to the change of temperature thus introduced before a reading is taken.]

Having ascertained the rate of normal transpiration, try the effect of blocking up the openings of the stomata by smearing (1) the upper, (2) the lower surfaces of all the leaves with vaseline.

You may also determine the amount of water lost by a plant in a given time by **weighing.**

Take two similar test-tubes and three-quarters fill each of them with water; fit them loosely with corks. Bore a hole in one cork and pass a leafy plant stem through this hole so that the end of the stem dips well under the water. Weigh each test-tube carefully. Let them both stand, if possible, in the open air on a sunny day for a couple of hours.

Then weigh both tubes again. The one destitute of a plant will be found to have lost very little water (as determined by the diminution in weight), and this will show how much has been lost by evaporation.

Weigh the tube containing the plant; this will be found to have lost considerably more water. The loss of weight will indicate—

1. Loss due to evaporation, together with
2. Loss due to transpiration.

Since the first tube will give a measure of the loss due

to evaporation, this amount must be subtracted (if it can be measured at all) from the total loss of weight in the case of the tube containing the plant, and the remainder will give, roughly, the loss due to transpiration alone.

Path of the Transpiration-current.—In order to determine the channel by which the water passes up through the stem to the leaves, use may be made of dyes which will stain the walls with which they come in contact.

Prepare a glass of water in which some eosin or safranin has been dissolved [the **water-soluble** form of the dye must be used]. A very small amount of the dye is required in order to give the water a fairly strong colour.

Bend a shoot of Amarantus, or Balsam or other plant under the surface of the liquid, and cut it through the part immersed in the water. This precaution is to prevent the entrance of air into the conducting channels.

Allow the plant to remain for several hours, so that the water may rise in the stem to supply the place of that lost by transpiration from the leaves.

By-and-by the stem will be found to be streaked with red, and the veins, or vascular bundles of the leaves, may also exhibit the same colour.

Cut transverse sections of the stem, and examine them with a good hand-lens. It will be seen that the **Xylem** only is coloured.

Next take a branch of a tree—Neem answers very well—and cut a fresh surface **under water,** about two inches from the lower end of the cut-off branch. This is to ensure, as in the last instance, that the air does not get in to block up the water-conducting channels.

Remove a ring of the rind from the stem (taking care to cut it down to the wood) a little above the level of the water and below the leaves.

If the water rises in the tissues of the rind (Phloëm, cambium, or cortex) the branch will presently wither.

Take a similar branch, and remove the rind for about

an inch from its lower end, and carefully block up the end of the wood with lard or coco butter. Immerse the twig in water.

If now the water rises in the rind the twig will remain fresh, but if it rises in the wood it will presently wither, because you have blocked the ends of the xylem cells and vessels with the **fat,** and so little water finds its way in through the side walls on the outside of the exposed wood as to be almost inappreciable.

Suction Force of Transpiration.—Cut a leafy shoot of Neem, or Tecoma or some similar plant under water and fix it tightly to the end of a glass tube about 2 ft. long. Now fill the tube with water and dip the open end in a trough of Mercury. Take care that no air gets into the tube and fix the apparatus to a stand. Note that the mercury rises in the tube as the water is sucked by the transpiring shoot.

Water Stomata.—Some plants not only excrete **watery vapour,** but actual **drops of water.**

After a warm day, when the night happens to be cold, the air is capable of holding less vapour in suspension than during the day. But owing to the warmth of the soil, the roots may be still stimulated to absorb water, which is then pressed up the stem to the leaves, and it may be in excess of what can be got rid of by transpiration alone ; and unless a special means were provided for its escape, it might escape from the cells and clog the air-passages.

Examine the common **Tropaeolum** in the early morning ; its leaves will be found to be sprinkled with drops of water. These may be so numerous as to run together, forming a pool on the leaf. This water has been **excreted as liquid** by means of a special apparatus in the leaf known as a water-gland, and does not owe its presence to dew.

Many plants, e.g. **Fuchsia,** have water-glands at the end of the leaf-teeth, and sections of the leaves at these places easily demonstrate the structure of these glands.

CHAPTER XXVI

IRRITABILITY, MOVEMENTS

THE fact that plants are irritable is betrayed chiefly in the power which they have of executing movements in response to any stimulus which can act on the protoplasm. Some of these movements are due to the stimulating action of external forces; other movements are more directly associated with the hidden processes of growth and the like.

1. **Automatic or Spontaneous Movements.**—Examine the small lateral leaflets of the Telegraph Plant (*Desmodium gyrans*) and note that these leaflets make a circling movement. The movements are quite rapid in a moist warm atmosphere.

Nutation or nodding movements due to unequal growth is very well seen in the growing flower stalk of Onion, and also in the unfolding of leaves and flower buds. In the unrolling of fern leaves more growth takes place on the underside. The nutation here is called **Hyponasty.** In the opening of flower buds and of most leaves, more growth takes place on the upper side and the nutation movement is called **Epinasty.**

2. **Movements induced by Mechanical and Chemical Stimuli.**—Examine a plant of the White Bryony (**Bryonia dioica**), or, still better, the Passion-flower. Study the form of the tendrils, and the spontaneous nutation exhibited by them.

Gently stroke a tendril on its upper surface, and treat another one similarly on its under surface. Carefully observe the result, which in warm weather will become apparent in a few minutes.

Study the characters of tendrils which have laid hold of a support, and pay especial attention to the mode of coiling of such a tendril. Draw it as faithfully as you can.

Take a plant of **Mimulus** and observe the form of stigma; it consists of two open flaps, one pressed back against the corolla, the other one against the style, Gently touch the inner (exposed) surface of a stigma lobe, and note the immediate movement in response to the stimulus.

Examine the flowers of the Common Barberry, and note the six stamens, each pressed back against a petal. With a bristle gently touch the anther. Then similarly touch the inner face of the filament, and observe the consequent movement. Try to find which part of the stamen is most sensitive to contact. Note the effect of this change of position when the stamens are stimulated by an insect visiting the flower.

Dependence of Irritability on the Presence of Oxygen.—In order to show that the execution of the movements of the plant are dependent on the presence of Oxygen, we will place a flowering sprig of Barberry into a bottle in which the air is displaced by an indifferent, innoxious, gas like Hydrogen.

Fit up a Hydrogen apparatus, and pass the gas through two wash-bottles containing caustic potash solution in order to free it from impurities; then lead it into the bottle containing the plant. It escapes through a second tube which must dip under water. In this way, by sending a rapid stream of hydrogen through the apparatus, the air is soon washed out of the bottle, and the plant is left in hydrogen with no oxygen.

After it has been in this for a couple of hours, the stamens will be found to have lost their irritability. They are no longer able to execute spontaneous movements.

Stimulation of Sundew.—Place a small fragment of food (white of egg) upon the leaf of a Sundew plant. Observe that, as the result of this stimulus, the distant tentacles curve towards the object. Keep the Sundew for a time in an atmosphere devoid of oxygen (in an atmosphere of

hydrogen, as above), and then repeat the experiment of stimulation.

Do the same after subjecting it for a time to the action of chloroform vapour.

In neither case will a movement ensue on stimulation. Determine the length of time taken before arrest of movement occurs. Again place these plants in fresh air, giving them time to recover from the effects of loss of oxygen and of poisoning respectively, and the movements will commence on further stimulating them. [N.B.—The action of the chloroform must not be allowed to go on for many minutes.]

Place the plants in a glass box cooled with ice for a time, and observe that stimulus is not followed by movement.

The same cessation of response to a stimulus is produced by keeping them too warm, but in the latter case death soon ensues after the temperature limit of irritability (about 40° C., 104° Fahr.) has been overstepped.

Recovery follows, however, if the plants survive, when the temperature is brought back to the normal range.

These experiments show that plants are only able to **respond to the stimulus** (or, as we say, are in an **irritable** condition) as long as the protoplasm is in a healthy state.

Observe also that the effect is disproportionately large when compared with the stimulus employed.

[Some plant-movements, however, are independent of protoplasmic vitality. Examine the ripe capsules of a moss and when the capsule is open, you will see the cup-shaped rim is fringed with hair-like teeth. These can be made to open and close by varying the dampness in the air. Thus merely breathing upon them produces movement. This simple movement depends on the physical properties of the **dead** membranous tooth, and not at all on the living activity of protoplasm.]

Geotropism.—Many of the chief features of Geotropism may be studied on seedlings.

Take young seedling plants—Mustard, or Beans, or

Cress will do—and pin them by their middle in a **horizontal** position to an upright strip of wood supported for convenience in a flower-pot of soil.

Put a bell-jar over the seedlings, and keep the atmosphere damp by means of wet blotting-paper.

After a quarter of an hour, note the position of the plants. When some hours have passed, again observe the positions of—

1. The root, positively geotropic.
2. The shoot, negatively geotropic.

That the position of the root is not a merely passive one due to its weight, but that it is **actively** assumed as the result of the stimulus of gravity, may be shown in the following way.

Take a kidney bean seedling, which has a stout, strong, primary root of about 1½ inches (4 cm). Fix it horizontally to a support by means of pins stuck through the cotyledons. After a time the end of the root will become directed vertically downwards. Allow it to grow into a small cork which has a hole bored partly through it.

Place a small vessel of mercury under the end of the root protected with its cork tip, and observe that the root exercises considerable pressure on the floating cork—so much so that the hinder part of the root is thrown into a steep curve, due to the upward pressure exerted by the mercury on the growing end of the root which is striving to force down the cork into the liquid.

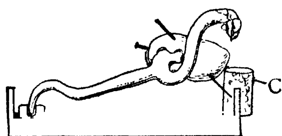


FIG. 83.—To illustrate a method of showing that Geotropism is an expression of irritability. *Hg.*, mercury contained in dish; C, cork, to which the bean plant is fixed by pins passing through the cotyledons. This cork is fixed to the side of the dish by cutting out a slice from the centre of the cork, and the two sides then grasping the dish sufficiently firmly. For explanation, see the text.

[The cork may be dispensed with, and then the root-apex will grow down into the mercury, although in doing so it will displace much more than its own weight of the metal.]

That it is only the growing parts of plants which can exhibit the curvature may be demonstrated by marking seedling roots, as in the previous experiments on the localization of active growth, and observing that the curvature only occurs in the **still growing** portions.

Also take a potted Geranium plant; lay the pot on its side and observe the curvature produced on the stem. As this will be interfered with by light, the plant experimented should be covered over with a blackened box so as carefully to exclude **all** light.

Similarly take a growing grass stem and peg it down to a horizontal position on the soil. Carefully notice where the negatively geotropic curvature is manifested.

In order to investigate the question as to what part of the growing organ is able to receive the stimulus which causes it to assume a fixed position with regard to gravity, we will examine some seedling Beans—kidney beans answer very well.

Pin them out on supports so that at first the roots hang vertically.

Cut off small pieces from the ends of the roots by transverse cuts, removing different lengths in the different seedlings.

Then turn the support so as to bring all the roots of the seedlings into a horizontal position.

Observe that none of those from which you have removed more than the extreme lip will be now affected by the stimulus of gravity, although you may not have cut as far back as the actively elongating region.

Take some other seedlings and place them in a horizontal position for ten minutes or so, then cut off the tips of the roots.

After a while notice that the curvature due to gravity manifests itself.

Compare them with uninjured roots in respect of—

1. The time at which the curvature becomes apparent.

2. The amount of curvature produced.

Take another lot of seedlings and place them in a medium destitute of oxygen.

For this purpose a board is prepared which will fit into a long wide-mouthed bottle in such a way as to be held tightly by the cork which closes the mouth of the bottle. Four or five seedling beans are pinned by their cotyledons on to the board in a horizontal position. When the board and the seedlings are inside the bottle, water, which has been boiled in order to expel the air dissolved in it, is poured in until about half the seedlings are covered by it, and the cork is then inserted. After a few hours the roots of those seedlings above the surface of the water should show a downward curvature, whilst those immersed in the liquid should exhibit no change in the direction of growth.

On pouring out the water, after this observation has been made, and readmitting air to the roots, they will curve in the usual manner.

The experiment may be made in another way. The seedlings are placed in the bottle as before, but the cork, which must be a thoroughly well-fitting one, is bored with two holes, through which two glass tubes are passed. One of these reaches to the bottom of the bottle, whilst the other is pushed for a short distance only through the cork. This latter tube is connected by means of a short indiarubber tubing with a glass tube dipping under the surface of some water, whilst the other is connected with a hydrogen generator delivering purified hydrogen. The gas is allowed to pass for a couple of hours through the bottle containing the seedlings, and then, before it is disconnected, the indiarubber tubing of both glass tubes is closed by clips.

The bottle is then put on its side, and if there is no leakage and entrance of oxygen, there will be no curvatures effected.

[It must, however, be remembered that it is impossible

to prevent a certain amount of gaseous diffusion through the cork and indiarubber.]

After the lapse of a day air may be freely admitted into the bottle, when the curvatures will commence.

[The klinostat may also be employed to investigate geotropic phenomena. If the apparatus should be accessible, place a seedling in a bottle, so that its root, when fixed on the klinostat, is horizontal.

If the seedling be now rotated, it will continue to grow out in the horizontal direction, for the reason that, before the stimulus which has been received by one side has resulted in the execution of a movement, a similar stimulus has been conveyed to the whole circumference of the root, and consequently, as every longitudinal streak of the root has been similarly stimulated for an equal time with equal strength, there is no reason why the root should curve to one side rather than another.]

Many flowers are very sensitive to the action of gravity.

One of the most striking instances is afforded by the garden varieties of Ranunculus.

If flowers, on long stalks, of these plants be cut and placed in water, and inclined at various angles with the vertical, it will be found that they will twist on the flower-stalks so as to grow directly against gravity, i.e. they are negatively geotropic. This is best seen when the plants are placed in the dark, as the directive influence of light does not then come into play.

Another plant which may be studied is the Common Daffodil. The flowers nod on their stalks, but they make a definite angle with the vertical direction of gravity. This angle may be altered by bending over the flower-stalk, but the flower then alters its position on the stalk, so as to again resume its definite position with regard to gravity.

Hydrotropism.—Some parts of plants, notably the roots,

are affected by the proximity of water, which may thus act as a stimulus and provoke movements.

Hydrotropic movements may be shown by growing pea seedlings in a sieve of wet sawdust. The meshes of the sieve should be large enough to allow the roots to grow down through them.

If now the sieve, with its seedlings, be watched after the roots have projected through the meshes, it will be found that, instead of continuing to grow vertically downwards, the roots will curve so as to creep along the damp surface of the sieve. This they do in obedience to the hydrotropic stimulus afforded by the damp sawdust, and which is sufficiently powerful to overcome the geotropic one due to the influence of gravity.

Heliotropism.—Most plants react towards the stimulus of light in such a way as to place their various parts in positions having a definite relation to the direction of the light-ray.

Take a wide-mouthed bottle, about four or five inches in height, stretch across its mouth some cotton netting, such as can easily be obtained from a linen-draper, fill the bottle quite full of water, sow a few cress seeds on the net, and put into complete darkness.

After a time the seeds will germinate, and the roots will grow downwards to the water through the meshes, whilst the shoots will grow into the air. The netting is to hold them in position, so the meshes must not be too large.

When the plumule has grown to a length of an inch or so, the bottle may be removed to a cardboard box, carefully blackened inside, with a very narrow slit cut in one of the walls. This is to admit a little light.

After about three hours it will be seen that the shoots have turned rather sharply towards the light, whilst the roots have all turned away from it.

The shoots are, therefore, **Positively Heliotropic**; the roots are **Negatively Heliotropic.**

Especially note the position taken up by the blades of the seed-leaves. They are Diaheliotropic.

The effect of different constituents of white light in calling forth movement may be studied by means of the coloured screens used to investigate the action of different rays on assimilation.

The vessels containing the coloured solutions, together with the cress seedlings, may be covered over with blackened paper, a slit being cut in one side.

The two experiments, with the blue and yellow solutions, should both be performed simultaneously, taking care that the external conditions are as similar as possible in the two cases.

The plants will not behave at all alike: carefully observe the difference.

Influence of Light in causing Movement in Chlorophyll-containing Protoplasm.—Place a leaf of Hydrilla in a drop of water on a glass slide, cover with a cover-glass, and examine under the microscope. The chlorophyll will be found to lie in the peripheral protoplasm lining the cell-wall, and many granules will present their flattened-surface to the observer. Allow fairly bright light (**not** direct **sunlight**) to impinge on the leaf by means of the microscope mirror. In a few minutes the chlorophyll granules will be found to have retreated to the lateral walls of the cell, leaving the upper and lower surfaces nearly empty. The granules likewise present their edges to the incident light. By darkening the object the granules again spread over the surface of the cells as before.

It is to this fact that the pale green of leaves on a bright summer's day is due, and the truth of this can easily be proved by placing an opaque object—e.g. a piece of tinfoil—over part of a leaf in the daytime, whilst the rest of the leaf is exposed to direct sunshine. After a while remove the tinfoil, and its form will be reproduced as a dark-green patch on the paler green surface of the leaf.

Observe a Geranium plant which has been left growing

in the window of an ordinary room. Note the position of the stems, of the leaf-stalks, and especially of the **leaf-blades,** to the direction of the incident light. The leaf lamina tends to lie at right angles to this direction, and thus the blade is **diaheliotropic.**

Compare with this the appearance of a Fuchsia grown under the same conditions.

[If it should be possible to procure a **klinostat,** which is simply an instrument for slowly causing the plant to rotate, you can eliminate the directive action of light; and thus a plant rotated in front of a window will exhibit no heliotropic curvatures, but will grow straight and symmetrically.

The reason of this is, that as equal angular distances, and consequently equal portions of the circumference of a plant, together with all its organs, are exposed to the stimulus for equal times at sufficiently shortly recurring intervals, all the parts are **alike** stimulated, and hence there is no reason for any movement to take place to one side rather than to another.]

Many shoots, however, are not positively-, but either negatively- or dia-heliotropic.

The climbing shoots of the Ivy are an example. They will place themselves, when possible, so as to spread in a plane at right angles to the incident rays of light. Observe an Ivy which is climbing up a brick wall. Note its behaviour—

1. While climbing up the vertical side.
2. When it reaches the top.
3. When it has grown beyond the top surface.

Many shoots, especially of creeping plants, are positively heliotropic while the leaves are unfolded or nearly so, but become diaheliotropic afterwards.

Another set of movements which depend upon light are the so-called 'sleep' movements.

Carefully note (and sketch) the appearance of the leaves of a Mimosa plant growing in the day light.

Examine the same leaves after dusk has set in. Also examine as many plants as possible with pulvini at the bases of the foliage leaves and carefully study the changes of position in—

1. Ordinary diffuse daylight.
2. The bright sunshine in summer.
3. The dusk of the evening.

Some flowers are also very sensitive to changes in the light.

Examine a Daisy flower during bright daylight, and observe the same flower again in the evening. Once more examine it in the morning. Carefully note what parts are affected so as to execute movements.

A very striking plant is the Tobacco plant (Nicotiana). Observe the withered, inconspicuous appearance of the flowers by day, and compare this with the same flowers in the twilight.

[Other flowers may be made to open or close by raising or lowering the temperature; the reaction will follow quite irrespective of illumination—e.g. in Crocus.]

PART IV

CLASSIFICATION AND EXAMPLES OF NATURAL ORDERS OF FLOWERING PLANTS

CHAPTER XXVII

PRINCIPLES OF CLASSIFICATION

Principles of Classification.—Underlying the vast range of forms to be seen in the plant kingdom, we find striking resemblances or **Affinities** in the structure of members of certain plants, which point to a real relationship between them. These resemblances or affinities, which indicate the existence of relationship amongst plants, has led to the recognition of different **degrees** of affinity, and thus we find that **Species** are grouped into **Genera, Natural Orders, Cohorts, Series,** etc., thus comprising the whole **Vegetable Kingdom.** The **Linnean** system of classification which was in use until the middle of the last century, was not based on relation amongst plants. It was based on a single character of the flower, viz., the number of stamens, which though convenient for practical use, became less and less satisfactory with increased knowledge, as it obviously brought together plants having no 'affinity' and kept apart those felt to be closely related. This **Artificial** system of Linnaeus, has been practically replaced by two modern systems of classifications of (1) **Engler,** and (2) **Bentham and Hooker.** Their aims have been to express the relationship between different plants. The system of Bentham and Hooker is mostly in use in this country and so has been followed in this book. According to this

system, the vegetable kingdom has been divided into two sub-kingdoms, viz.

1. **Cryptogamia**—popularly known as the flowerless plants. These are reproduced by spores and hence are called **Sporophyta** or spore plants.

2. **Phanerogamia**—popularly known as the flowering plants. Also called **Spermaphyta** or seed plants. The Phanerogams are classified into **Angiosperms** or covered seeded plants and **Gymnosperms** or naked seeded plants. The Angiosperms are again divided into Dicotyledons bearing two opposite cotyledons in the embryo, and Monocotyledons which bear only one cotyledon in the embryo. The Dicots and Monocots are further divided into Cohorts, Natural Orders, Genera and Species. Before turning to consider the principal groups or orders of plants, it will be better to explain the new terms, we have just now come across, more fully.

Species.—A collection of individuals which resemble each other, as closely as they resemble their parents and their offsprings. Species resemble each other in all their important characters. Under certain conditions however, generally under cultivation, plants belonging to the same species vary from one another in size, colour, form, and other minor characters as in different kinds of banana, oranges, etc., and we get **Varieties. Races** are permanent varieties.

Genera.—Certain species resemble more nearly each other than others. Generic characters are taken from reproductive organs, and specific from both vegetative and reproductive organs. Hence a genus is defined as a collection of species resembling each other in the structure and general characters of their reproductive organs. Thus when we consider Ficus bengalensis, F. Cunia, F. religiosa, F. hispida, we notice that they are alike in respect of their flowers, inflorescences, fruits and seeds. It is mainly in the shape of the leaves that they differ and we group them into one genus **Ficus.**

Natural orders.—Several allied genera are grouped into a Natural Order, laying special stress on the resemblances of flowers, fruits and seeds. Thus, Radish, Cabbage, Mustard, are all included in the Order Crucifereæ.

Cohorts.—Several allied orders are grouped into a cohort. Thus Crucifereæ, Papavaraceæ, Capparideæ are grouped as Parietales, all having parietal placentation.

The following general points of structure should **always** be determined in dealing with a plant, whether they are specially indicated in the pages which follow or not:—

1. The general habit, whether woody or herbaceous.
2. The hairy or glabrous character.
3. The racemose, cymose, or solitary nature of the inflorescence.
4. The bracteate or ebracteate character of the flowers.
5. The regular (actinomorphic) or irregular (most often zygomorphic) form of the flower.
6. The number and position of the sepals and petals.
7. The coherence or adherence (e.g. gamosepalous calyx) of the parts of the flower.
8. The hypogynous, perigynous, or epigynous character of the stamens.
9. The gynæcium, whether superior or inferior, whether of one or more carpels.
10. The ovary, whether apocarpous or syncarpous.
11. The placentation, its position.
12. The form of the ovule, whether orthotropous, campylotropous, or anatropous.
13. The fruit, its general character and mode of dehiscence.
14. The seed, whether albuminous or not.
15. The floral diagram must always be made, and the position of the mother-axis with regard to the flower carefully marked. This last is a most

important point, for it is only when it is attended to that the different diagrams can be compared with each other; the mother-axis serving as a definite starting-point for the 'orientation' of all the parts of the flower. A few illustrative diagrams will be given from time to time, but it is best for you to make your own from the results of your own independent observation.

CHAPTER XXVIII

RANUNCULACEÆ, ANONACEÆ, MAGNOLIACEÆ

Ranunculaceæ.—These are herbs or climbing shrubs, often growing in marshy places. Leaves usually radical or alternate, rarely opposite. Stipules none or adnate to the petiole. Flowers regular or irregular, usually hermaphrodite. As examples the following plants may be selected.—Ranunculus, Clematis, Monkshood, Larkspur and Kalajira (**Nigella sativa**).

Ranunculus.—Annual or perennial plants. **R. sceleratus** is common in Bengal and **R. muricatus** in the Panjab. Note the erect herbs with alternate, exstipulate lobed leaves. Leaves radical, stalked; stem leaves, sessile. Flowers, pale yellow. In the flower, observe—

1. The inferior calyx of five, sepals.
2. Corolla of five free petals. The nectaries at the bases of the petals. (These are regarded either as modified petals or stamens).
3. The many stamens. Note the mode of insertion of the anther on the filament and of dehiscence of the mature anther.
4. Gynæcium, superior, of many carpels, all free; each with one ascending ovule. Note that the ovule arises from the base of the ovary.

Cut the flower down the middle, so as to clearly show that the arrangement is hypogynous.

5. The fruit is an etaerio of achenes.

Draw a floral diagram and make out the floral formula. K5, C5, $A\infty$, $G\infty$.

Clematis.—Examine flowers, buds and fruits of any wild Clematis. A cultivated variety may be substituted, but

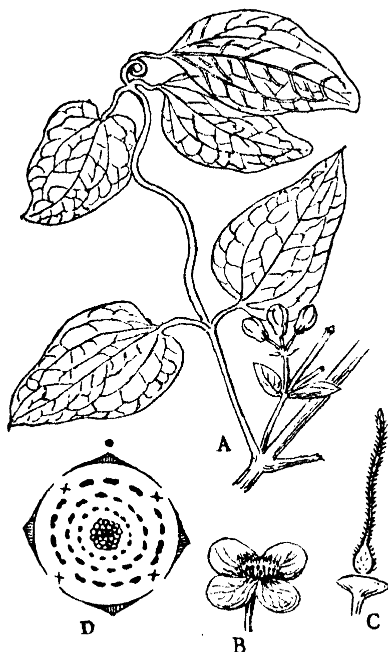


Fig. 84.—Clematis A, inflorescence; B, flower; C, pistil; D, floral diagram.

then it may exhibit some variation in the number of its parts. Note—

1. The flowers have got only one whorl of perianth and since their allies possess both, the term calyx is used whether sepaloid or petaloid. Note their arrangement in the bud (Valvate).
2. The many free hypogynous stamens. Specially observe how the stamens, as the anthers shed their pollen, bend outwards.

3. The gynæcium, superior and apocarpous. Note the silky hairs, and observe the stigmas only become mature as the inner anthers ripen.
4. The absence of nectaries. In plants growing in the open, observe the **pollen-collecting** insects at work on the flowers.
5. The fruit—a number of one-seeded achenes. Note the development of the beard.
6. Floral formula. $K4, C0, A\infty, G\underline{\infty}$.

Both the above forms are radially symmetrical, or **actinomorphic** flowers.

Next we will examine the **Monkshood** and **Larkspur.** Both of these possess **irregular** flowers. They can, however, be divided into two symmetrical halves by a median longitudinal section, so they are often termed **Zygomorphic** flowers.

In the Monkshood observe—

1. The five inferior blue sepals. The posterior one is large and hood-shaped ; the two lateral ones rather flat ; the anterior one the smallest.

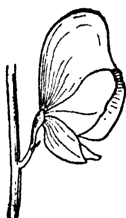


FIG. 85.—Monkshood (*Aconitum*). Side view of flower.

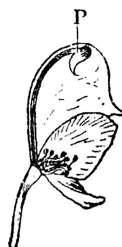


FIG. 86.—Monkshood. Section of flower. P, petals.

2. The inferior petals. Two only of these will be readily seen, and they form curiously shaped nectaries lying in the sepaline hood. Carefully pull one off, cut it down the middle in order to see the honey gland. The other three (sometimes more) petals are very small.

3. The numerous free hypogynous stamens. Carefully note the positions assumed by the unripe, the mature, and the oldest anthers which have already dehisced. If possible, observe how the arrangement ensures that large insects visiting the honey are dusted with honey.

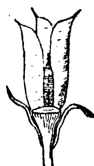


FIG. 87.—Monkshood. Fruit of follicles.

4. The superior apocarpous gynæcium. The carpels, however, sometimes cohere slightly at their base. Carefully observe that the stigmas are not mature till the anthers have all dehisced. Note the different positions assumed by the immature and ripe stigmas respectively. Correlate this with insect visits.
5. The fruit—its structure and dehiscence.

Larkspur.—There are several sorts cultivated, and they differ somewhat from each other. One of the common cultivated kinds is **Delphinium elatum**, and it or its varieties will do for examination.

Take a spike of the Larkspur, and, cutting off one of the flowers, observe—

1. The five inferior blue sepals. The posterior one is prolonged into a long, rather crumpled, straight horn.
2. The petals, usually four. The two upper (posterior) ones are prolonged as spurs backwards into the hollow horn-like sepal. Notice the glandular nectaries at the end of the spurs, and also the firm, rigid nature of the anterior edge of the petals. The two lower (anterior) petals form a platform on which insects may rest. Note the hairs, and also the ease with which the two petals are depressed. Observe that when so depressed, the anthers of the stigmas protrude between them.

3. The stamens, free and hypogynous. Carefully observe the positions taken up by the stamens at different ages, and compare the younger and older flowers together in order to determine this point.

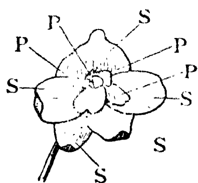


FIG. 88.—Larkspur. P, petals; S, sepals.

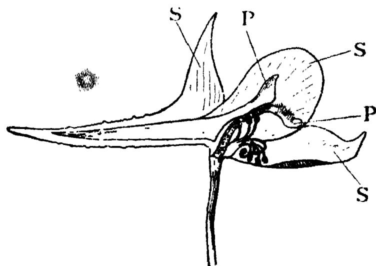


FIG. 89.—Larkspur (*Delphinium*). P, petals; S, sepals.

4. The superior apocarpous gynæcium. The structure and contents of the carpels. The behaviour and positions of the ripe and unripe stigmas respectively. These points can best be appreciated by cutting the flower into two halves in the plane of its symmetry.
5. The character of the fruit and its mode of dehiscence.

In order to fully appreciate the meaning of the arrangements of the part of this flower, it is essential that they should be observed when still growing at a time when insects are visiting them.

Note—

(1) Where the insect lands.

(2) How it comes in contact with either the stamens (in young flowers) or the stigmas (in old flowers).

Kalajira (Nigella sativa) is commonly cultivated for its seeds which are used as a condiment and also are a preventive against the attacks of insects upon clothes. Note the peculiar pocket-like nectaries within the petaloid sepals and the partly united carpels—an abnormal condition in

this family. Note also the mode of dehiscence of the capsular fruits. Floral formula, K5, C0, A∞, G $\underline{(5)}$.

Anonaceae—(Fig. 90). These are mostly tropical plants often climbing and sometimes aromatic. Let us first examine **Anona squamosa,** the Custard Apple plant of India. Note the shrubs with alternate, exstipulate, simple leaves. These are nearly evergreen plants. The flowers are about an inch long. In the flower note :—

1. Three small sepals; triangular; united at the base.

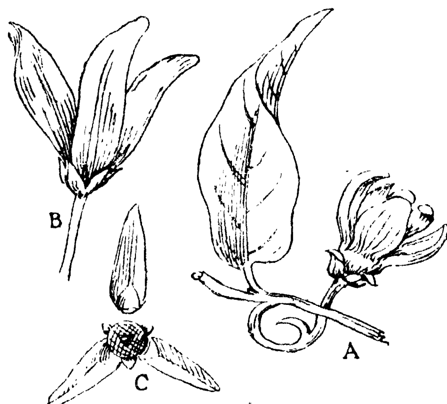


FIG. 90.—A, flower of *Artabotrys odoratissimus* ; B, flower of *Anona reticulata* ; C, same showing the parts of the flower.

2. Petals-valvate ; six, 2-seriate. Those of the outer series thick, rigid, connivent and larger than those of the inner. Inner ones, minute or wanting.
3. Numerous stamens. Anther cells narrow ; anthers concealed by overlapping connective.
4. Carpels—many, subconnate ; style—one oblong ; ovule—solitary, erect.
5. Fruit, edible, yellowish green. An ovoid mass of confluent ripe carpels.
6. Floral formula-K (3), C 3+3, A∞, G $\underline{(\infty)}$.

Next examine **Artabotrys odoratissimus.** Note the climbing habit. Specially observe the characteristic hooked peduncles and petals connivent at concave base (Fig. 90,A). The fruit here is a head of berry like free carpels.

Other common plants belonging to this family are **Anona reticulata** the Bastard Apple, **Polyalthia longifolia**—an avenue plant, etc.

Magnoliaceae—(Fig. 91). The flowers are usually aromatic and very showy. Leaves alternate, simple. Observe the buds enclosed in the connate, convolute, caducous

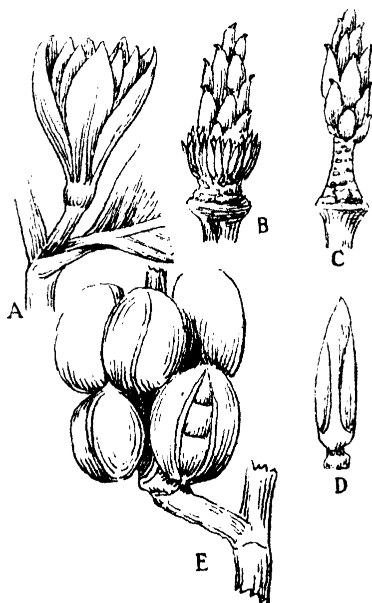


FIG. 91.—Michelia Champaka, A, flower ; B, same with perianth removed ; C, with pistils only ; D, stamen ; E, fruits.

stipules. Perianth of similar sepals and petals and many seriate. In Champaka **(Michelia Champaka)** note that the carpels are in a loose spike on a stalked gynophore and that in Magnolia **(M. pterocarpa)** carpels are densely packed on a sessile gynophore.

CHAPTER XXIX

PAPAVERACEÆ, CRUCIFERÆ, VIOLACEÆ, CARYOPHYLACEÆ

Papaveraceae—These are herbs with milky or coloured juice (Fig. 92).

The Mexican Poppy **(Argemone mexicana)** one of the commonest wayside weeds will serve as our first example. Collect a few plants with flowers and fruits. Observe—

1. It is a prickly plant and when scratched, yellow juice comes out.
2. That the leaves are alternate, exstipulate, 3–7″ long, oblong, cut into pinnate spinous toothed segments half stem clasping and variegated green and white. Note the bright yellow flowers in a few flowered cymes with leafy bracts.

In the flower note—

1. Sepals—three (rarely 4), prickly ovate.
2. Petals—six (rarely 8), 2-seriate, caducous.
3. Stamens—many ; anthers, incurved.
4. Carpels—united in a one-celled ovary with 3–6, parietal placenta ; style, short ; stigma 4–6, lobed.
5. Fruit—a capsule opening by triangular valves, opposite the stigmatic lobes.

Next take up the Opium Poppy **(Papaver somniferum).** Note the milky juice. In the flower observe, 2-sepals 4-petals, and specially note the sessile stigma radiating from the centre. Fruit—a capsule dehiscing by pores.

The seeds of both the varieties yield oil. The drug

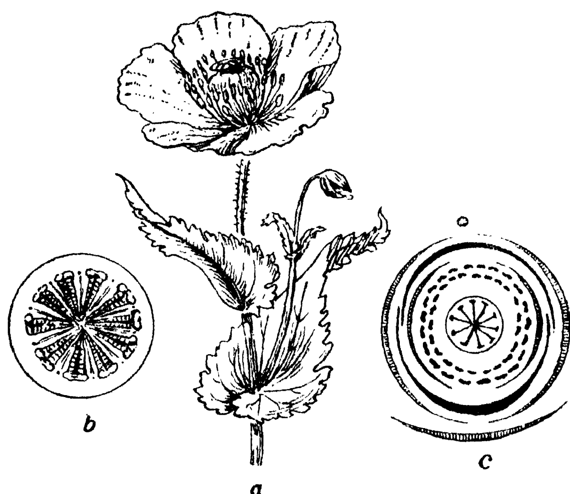


FIG. 92.—*Papaver somniferum*. *a*, flowering twig; *b*, section of a fruit; *c*, floral diagram.

opium is the inspisated milky juice collected from punctures made, in the unripe capsules.

Cruciferæ.—First examine a mustard plant—**Brassica juncea** (Fig. 93) which is cultivated in all the provinces and observe—

The corymbose raceme, and that the flowers are destitute of bracts (ebracteate).

In the flower observe—

1. The inferior sepals; observe their number (four) and their form. Note that they are arranged in two whorls.
2. The inferior corolla, of four petals. Carefully note their position with regard to the sepals.
3. The hypogynous andrœcium, of six tetradynamous stamens. Note the reason why two appear to be shorter than the other four. This is to be found in the fact that, like the sepals, the stamens are in two whorls. Carefully note the

glands (nectaries) at the base of the stamens of the lower whorl, and connect their presence with the **form** of the sepals opposite to them. Examine a flower when young enough to show the mode of insertion of the anther on the filament, and its mode of dehiscence.

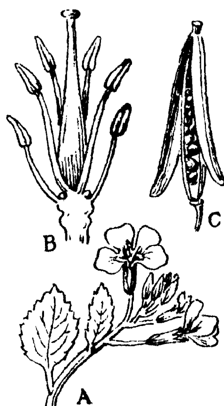


FIG. 93.- Mustard (*Brassica*), A, inflorescence; B, flower with sepals and petals removed; C, fruit.

4. In the centre of the flower is the superior gynæcium. Observe its pod-like form, with the bifid stigma and short style. Cut it across and observe that it is bilocular, and that the ovules are arranged on two placentas, which are connected by a partition wall **(dissepiment)** dividing the cavity into two loculi. [The placentas here form a strong frame, which in older ovaries can be detached from the carpels; it is the **Replum.**] Thus there are two rows of ovules in each loculus. Cut a transverse section of the ovary in order to see the vascular bundle (midrib) running down the middle of each carpel.
5. The form of the ovules, campylotropous. Press some of them out in water and make out the parts, specially noting the **curvature of the nucellus** characteristic of campylotropous ovules.
6. As the fruit ripens, note that the ovary lengthens and becomes **siliqua.** In the ripe fruit, observe that it **dehisces.** The replum remains with its attached seeds and the dissepiment stretched

across ; the rest of each of the two carpel-walls split away from below upwards.

7. Soak a seed in water. Dissect off the testa, and note the form of the embryo and the absence of albumen. Specially observe the position **(accumbent)** of the radical with regard to the cotyledons.

Thus the flowers will be seen to be actinomorphic, thalamifloral, with hypogynous stamens and superior bicarpellary ovary.

Examine sections of the ovary taken through young flower buds. You will see that the (false) dissepiment arises late, as an outgrowth from the placentas, and that it finally meets in the middle line, fuses, and thus (falsely) divides the ovary into two loculi.

Sometimes the dissepiment is incomplete, owing to the ingrowing edges failing to meet.

Radish (Raphanus sativus).—Note the swelling of the hypocotyle and root which the lower part of the plant undergoes.

In the racemose inflorescence observe the absence of bracts.

Compare the parts of the flower with the corresponding ones of the Wallflower, carefully tabulating the resemblances and differences.

In the ripening fruit, observe that

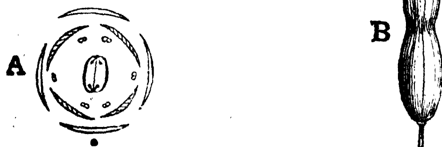


FIG. 94.—A, Floral diagram of cruciferous flower. B, Fruit of Radish.

although at first the ovary resembles, in essential features, that of the Wallflower, it soon deviates from it, and eventually the ripe fruit contains a few seeds, each

separated from its neighbour by a white pith-like substance. Cut transverse sections of the ovary at different ages, and determine how this white tissue originates.

Note that the ripe fruit is indehiscent; examine the seed and dissect the embryo, observing carefully how the radicle and cotyledons are placed and folded.

Shepherd's Purse (Capsella Bursa-pastoris).—In examining the flowers you may come across irregularities in the number of the parts of the flower, especially in the stamens.

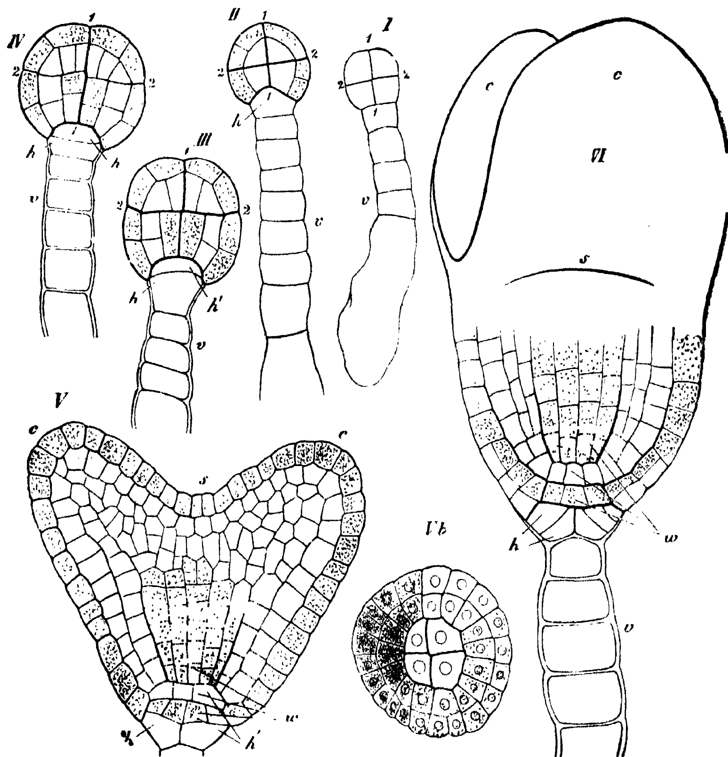


FIG. 95.—Stages in the development of the embryo of Shepherd's Purse. *v*, suspensor; *h*, hypophysis; *c*, cotyledon; *w*, growing point of root; *s*, growing point of stem.

Note also the position of the embryo in the seeds.

The embryo of Capsella is especially easy to use for studying the development from the fertilized oosphere to the mature embryo.

For this purpose take ovaries from which the petals are just fading, open them with needles, and remove the ovules from the replum. Place the ovules in a solution of potash on a glass slide and put a cover-glass over them.

Warm the slide over a gas or spirit-lamp flame, till the potash water begins to boil.

You must be very careful in this, as it is apt to show no signs of ebullition till it suddenly bubbles almost explosively, and then rapidly dries up, spoiling the ovules. Always have a wash-bottle of water ready to add a little water to the edge of the cover-glass if this should happen.

Note the diffusion of the green colour from the ovules, which will soon be bleached.

Gently press, by a series of squeezes, on the cover-glass. This will burst the ovules, and the young embryos will in some cases be pressed out of the curved embryo sacs, and the various stages in their development can thus be followed (see Fig. 95).

Repeat this process with the ovules of still riper ovaries, and having caused the extrusion of the embryos, make a series of drawings of the various stages observed.

The form of the younger embryos will be seen to be that of a cylindrical structure divided by cross walls into discs, with a roundish cell at each of the two ends; that at one (towards the micropyle of the ovule) end is very much larger and wider than the other. It remains undivided, and terminates the **suspensor.**

The smaller rounded cell at the other end forms most of the embryo. It divides into four cells by two walls at right angles to each other. Then a third wall at right angles to the other two appears.

The last cell of the suspensor just beneath this (smaller) terminal cell divides transversely into two cells, of which the one just below the developing embryo is termed the **Hypophysis.**

Next observe in an older embryo, the walls which appear in each cell cutting it into an inner and outer cell, thus separating off the epidermis. Within each of the inner cells a longitudinal wall is formed abutting on the transverse wall, and also on that separating off the hypophysis cell from the embryo. In the hypophysis note that the cavity now bulges into the embryo, and that a watch-glass-shaped wall is formed which abuts on the lower (hypophysis) end of the last-described wall. In this way there are formed the rudiments of the epidermis (Dermatogen), cortex (Periblem), and vascular cylinder or stele (Plerome).

The root end is formed from the hypophysis.

The above stages can **easily** be followed, and should be conscientiously worked out by means of comparison of a number of carefully made drawings of embryos in different stages.

Before leaving the orders already described try and construct for yourself a collection of the most important characters of these **natural** orders. In this way you will be led to appreciate the value of characters far more truly than if you merely **verify** the ordinal characters you already know in the various plants you examine. And the same remark will apply equally to those natural orders which follow.

Violaceæ.—A type of this order is seen in the Violet or the Heartsease. We select the latter plant for examination (**Viola tricola**).

Note the much-cut leaves and the large stipules. Also observe that, in addition to the flower arising from the axil of the leaf, there is a second (vegetative) bud. These accessory buds are not uncommon when flowers arise on a leafy stem and are not grouped into a regular

inflorescence. Note the two bracteoles or **Prophylls** on the peduncle of the flower.

In the flower observe—

1. Its zygomorphic symmetry; that is, it can only be divided in one plane, so that the two parts are similar to each other.
2. The inferior calyx, of five sepals. Carefully note the insertion of the sepals. This is somewhat obscured by the presence of the outgrowths or **Auricles.**
3. The inferior corolla, of five hypogynous petals. Carefully remove the anterior spurred one, and note that the spur arises as a dilatation of the anterior part of the petal. Note the presence of **hairs** on this petal. All the petals are marked with coloured lines leading to the centre of the flower.
4. The hypogynous andrœcium, of five stamens. The anthers cohere slightly by their edges. Note the projection of the connective above the anther. In the two anterior stamens observe the projections which originate from the filament, and which pass down into the spur of the anterior petal. Cut one of these down the middle and observe the glandular tip (nectary). This secretes honey or nectar, which is then stored in the petaline spur.
5. The gynæcium, superior. Observe the very peculiar form of the stigma. Carefully distinguish that part of it, protected with a lip, which is capable of receiving the pollen, and observe how the arrangement is calculated to promote cross fertilization. This can be best understood by watching an insect visit the flower and afterwards imitating the action of his proboscis with a bristle.

Cut across the ovary, and note that it consists of

three carpels united by their edges, and thus enclosing a single cavity. The ovules will be seen forming rows on each placenta.

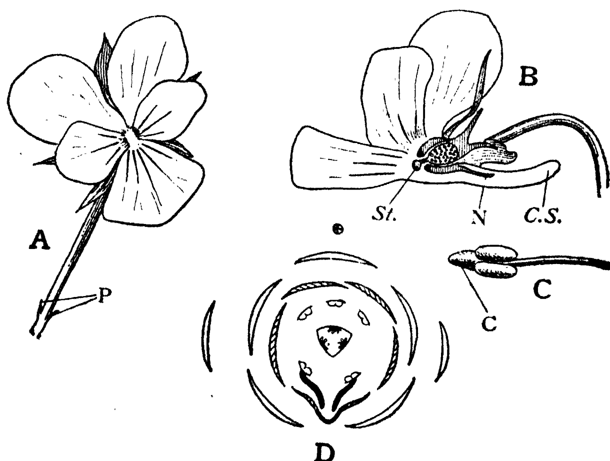


FIG. 96.—Heartsease (*Viola tricola*). A, Flower in full face; P, prophylls. B, Side view of flower cut open; *C.S.* spur of the corolla; N, nectary (appendage of a stamen); *St.*, stigma. C, Stamen, showing the flat outgrowth (C) of the connective above the anther. D, Floral diagram of a violet.

6. The dehiscence of the capsular fruit. It splits down the midribs (loculicidal) of the carpels, and in the process the seeds are sometimes jerked to a considerable distance.

Caryophyllaceæ.—The Mouse-ear Chickweed **(Cerastium vulgatum)** is common in the Punjab, and the Common Chickweed **(Stellaria media)** and the Pink **(Dianthus chinensis)** are very common in Bengal.

Note the swollen nodes, inferior calyx and corolla. The petals and sepals are all free. Note that some stamens at least, are provided with nectaries at their bases. In Pink, the nectar is secreted and concealed at the bottom of the corolla tube, formed by the long claws of the free petals. In Cerastium, note that the stamens are in two whorls but they do not open together, and ascertain for your self, the order in which they mature, by comparing flowers of different ages.

CHAPTER XXX

MALVACEÆ, LINACEÆ, RUTACEÆ, RHAMNACEÆ

Malvaceæ.—Examine the large flowered, cultivated plant, **Malva sylvestris** (Fig. 97). Note that each flower has an epicalyx of three bracteoles below the calyx. In the flower, observe—

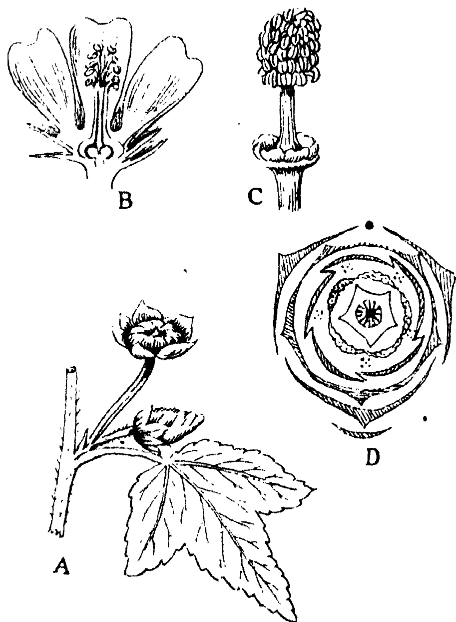


FIG. 97.—*Malva sylvestris.* A, flower and flower bud; B, vertical section of a flower; C, stamen; D, floral diagram.

1. Calyx—gamosepalous, of five sepals.
2. Corolla of five free petals. Note the twisted aestivation.
3. Stamens—many, monadelphous; find out how the style passes through the staminal tube; anthers one celled. Note the staminal column is adnate to the claws of the petals at the base.
4. The pistil, consisting of about ten carpels, multilocular, with one ovule in each loculus.

5. Fruit—a schizocarp.
6. Floral formula—K (5), C5, A($\underline{\infty}$), G(10).

In the Cotton plant (Gossypium) note the three large cordate bracteoles which must not be mistaken for sepals, and note the cottony seeds. The leaves in Cotton plants are palmately lobed.



FIG. 98.—A flower of Cotton plant (*Gossypium*).

Species of Hibiscus have the same general characteristics as species of Malva, but differs in having 5, carpels with 5, styles united below. Bhindi or Lady's Finger (**Hibiscus esculentus**) is largely cultivated for its fruits. The Chinese Rose (**H. Rosa-sinensis**) is a common garden shrub.

Linaceæ.—(Fig. 99). The cultivated Flax (**Linum usitatissimum**) is the most important member of this family. It is a small annual, freely branching, slender herb with fugacious blue flowers. In the flower, specially note dimorphism. Also the presence of minute staminodes alternating with the five stamens. The five celled superior ovary, later becomes ten celled due to formation of false septa. The fruit is a septicidally dehiscing capsule. The seeds yield oil.

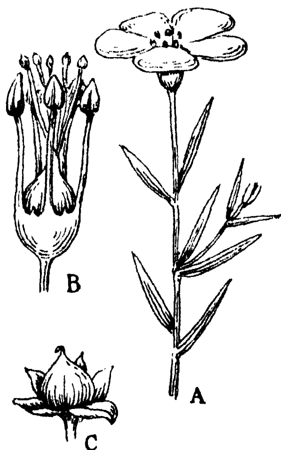


FIG. 99.—*Linum usitatissimum.* A, a twig bearing a flower; B, Stamens and Carpel; C, fruit.

Rutaceæ.—(Fig. 100). Examine **Citrus Aurantium** (Orange) or some other species of Citrus. Note the winged petiole, and leaves studded with

pellucid oil glands. Flowers-regular ; clustered in small cymes. In the flower note—

1. Gamosepalous calyx with 4–5 teeth.
2. Corolla—polypetalous ; 4–5, petals.
3. Stamens—many ; polyadelphous ; specially note the large disc inside the stamens, surrounding the ovary.
4. Pistil of 8—many carpels, syncarpous, multilocular axile placentation with several ovules in each loculus.

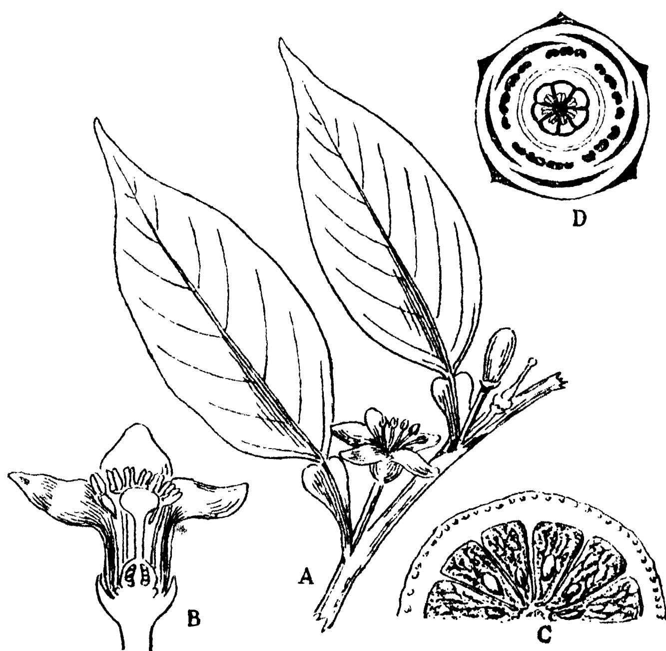


FIG. 100.—*Citrus aurantium*. A, inflorescence ; B, section of a flower ; C, section of a fruit ; D, floral diagram.

5. Fruit—a many-celled berry with a leathery rind and fleshy hairs within the cavities growing from inside the pericarp. The seeds are attached to the inner margins of the loculi, and they are often poly-embryonic.

Rhamnaceæ—(Fig. 101). We will take **Zizyphus Jujuba** as our example. It is widely distributed in this country. Note the alternate leaves with stipular thorns. Observe

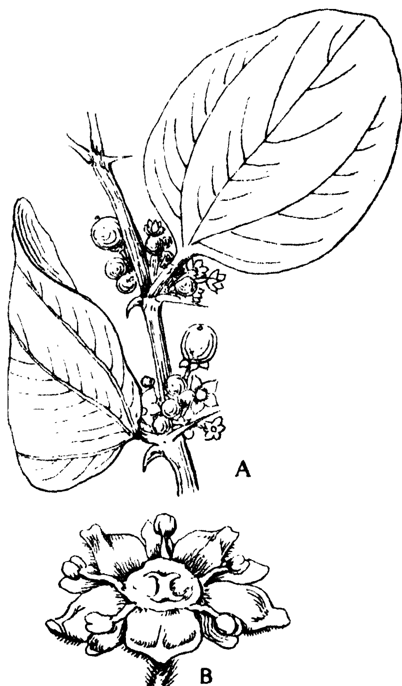


FIG. 101.—*Zizyphus Jujuba.* **A**, Inflorescence. **B**, Flower.

that the leaves are glabrous above and wooly below. Flowers are in axillary cymes. In the flower note,

1. Calyx of five sepals, gamosepalous.
2. Corolla of five petals, deflexed.
3. Stamens—five, opposite and often nestling under the petals.
4. Pistil—Bicarpellary, syncarpous, superior. Note the ovary is immersed in the surrounding lobed disc.
5. Fruit—indehiscent, drupaceous.
6. Floral formula—K (5), C (5), A (5), G (2).

CHAPTER XXXI

LEGUMINOSÆ, ROSACEÆ, CUCURBITACEÆ UMBELLIFERÆ

Leguminosæ.—Herbs, shrubs, or trees. Leaves, alternate, usually compound, rarely simple **(Bauhinia).** This order is divided into three sub-orders. Papilionaceæ include plants with irregular flowers having stamens,

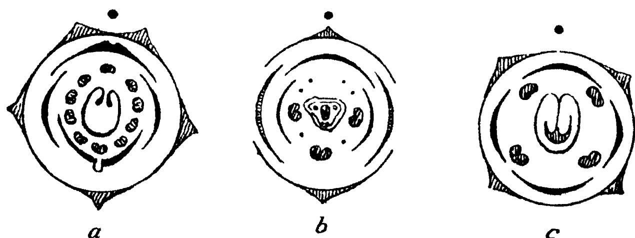


FIG. 102.—Floral diagrams of (*a*) *Papilionaceæ*, (*b*) *Cæsalpinæ*, and (*c*) *Mimoseæ*.

monadelphous or diadelphous, and the upper petal outermost. When in the irregular flowered Leguminosæ the upper petal is innermost and the stamens are free, the plants are put under sub-order Cæsalpinæ. Sub-order Mimoseæ include plants bearing regular flowers with indefinite stamens.

Papilionaceæ—Examine the common cultivated Pea, (Fig. 103) or any species of Lathyrus, Dolichos or Vicia. Dig up a plant and on the roots observe the **nodular swellings.** These are found very generally in leguminous plants, and they are produced by a very minute bacillus-like organism which occurs in groups of cells in the root, causing the tissues to grow out into these gall-like swellings. [The Bacillus lives partly on the substances produced by its host—but it does not procure the whole of its food from this source, but is able to cause the

free nitrogen of the atmosphere to enter into chemical combinations which can be further used by the plants. This is a very important property, and we may consider

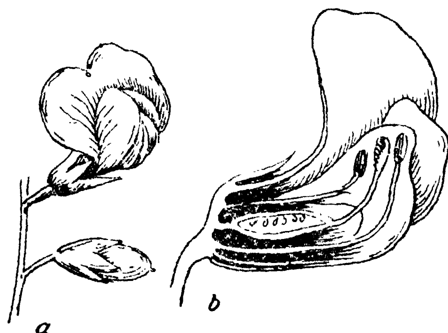


FIG. 103.—*Pisum sativum*. *a*, a flower and a bud; *b*, same in section.

that the Bacillus amply repays its host for the sustenance it demands, since it subsequently places nitrogenous compounds, formed by its agency, at the disposal of the host-plant. This living together of the Bacillus and the host is called **Symbiosis**, and each contributes to the welfare of the other. It thus differs from **Parasitism**, in which only one of the two organisms profits by the connection.]

Note the inflorescence—an umbel.

Observe the minute bract below each flower, and also the hairs at the base of the flower-stalks.

In the flowers make out—

1. That they are Zygomorphic.
2. The calyx, gamosepalous, with five teeth. Note the position of the odd sepal (whether anterior or posterior).
3. The irregular corolla; the large posterior Standard (or **Vexillum**), with a sharp fold down its middle. On each side are the two Wing petals (or **Alæ**), often partly coherent; below, and anteriorly of all, is the large boat-shaped Keel (or **Carina**)

made up of two petals. These really cohere for the greater part of their length both above and below, leaving however, an aperture at the apex. Carefully make out how the alæ are attached to the carina. Pull down the alæ, and notice the effect on the keel. As you go on pulling you will find that a heap of pollen is forced out of the aperture at the apex of the keel.

4. Remove the petals and cut off the calyx-teeth, and examine the andrœcium. It consists of ten stamens, of which nine are joined together by their filaments into one bundle, whilst the posterior one is free **(Diadelphous)**. Carefully note the passages left into the cavity of the stamen tube on either side of the free stamen. These lead into the chamber where the nectar is secreted and stored, and an insect visiting the flower inserts his proboscis through these apertures into the honey receptacle.

Examine the anther-end of the stamens. Note that five of them have club-shaped swollen ends to their filaments. These are scarcely seen if you look at the stamens in a half-grown bud. Their function is to push out of the end of the keel all the pollen from the ten stamens. The club-shaped stamens shed their pollen early, and you can only see that they really do bear fertile anthers by looking at young buds. [In some other leguminosæ, e. g. Lupins, these club-shaped stamens are really barren, having become entirely set apart for pushing out the pollen from the keel.]

You are now able to understand why a depression of the keel, which results from pulling down the alæ (as an alighting insect must do), will cause the extrusion of a mass of pollen.

5. Next remove the stamens, and observe the gynæcium, consisting of a single-stalked carpel, arising from the base of a cup, on the edges of which are situated the three exterior whorls of the flower. Note the long style, and capitate stigma.

   Slit the ovary down longitudinally in order to see the arrangement of the ovules.
6. Cut the flower down the middle with a sharp knife or scalpel to see that it is really perigynous. Note the nectar-secreting surface of the inner surface of the cup-like outgrowth of the receptacle. Nectar is especially secreted on the anterior surface of the inside of the cup.
7. Examine the fruit in various stages of ripeness. Note the dehiscence, by both ventral and dorsal sutures (the characteristic mode of dehiscence of a Lugume), and that the halves of each carpel become twisted as they open. This causes the seeds to be shot out to some distance from the parent plant.

Next examine the Common Vetch (**Vicia sativa** or **Vicia sativa, var. angustifolia**). Note first its lax trailing habit, and that it clings by means of tendrils to supports.

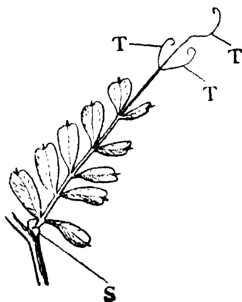


Fig 104.—Vetch (*Vicia sativa*) leaf. S, stipule; T, tendril.

Examine the leaves; note that they are pinnate, with five or six pairs of pinnæ, and that beyond them the remaining pinnæ are modified to form tendrils. Note the stipules at the base of the leaf, especially that the two are not alike, the lower of the two being larger, often with a projecting auricle. Usually a brown spot or blotch occurs on the stipule; this, in

sunny weather, may secrete honey, and is termed an **Extrafloral nectary.**

The flowers are borne, one or two together, in the axil of a leaf, and are of a purple colour. Make out the following points respecting them :—

1. The gamosepalous calyx, with its teeth nearly equal.
2. The corolla, built on the ordinary papilionaceous (butterfly) pattern common to all British Leguminosæ. Carefully note the relation of the alæ to the keel. Not only does a projection from the former fit into a corresponding depression in the latter, but it actually is adherent to it at this spot. Observe the manner in which the two petals of the keel cohere where the upward curve occurs. Note the canal in which the stamens and style (and stigma) lie.
3. The perigynous andrœcium. Diadelphous. Note the two windows on each side of the basal part of the free stamen through which insects can gain access to the honey. Note that in the open flower the anthers have dehisced, and are pulled down by contraction of the filaments. Compare the condition here with that in younger flowers and buds. Note the position of the nectary in the cup-like outgrowth of the receptacle.
4. The gynæcium, of a single carpel. Specially observe the brush of hairs on the style below the stigma. Take a flower and depress the keel as an insect would do, by gently pulling down the alæ, and note how the brush sweeps out the pollen from the canal of the keel.

Caesalpineæ (Fig. 105)—Examine the common Amaltas, **Cassia fistula** or the Kanchan (Bauhinia), or the Tamarind **(Tamarindus indica)**. Make out the following points:—

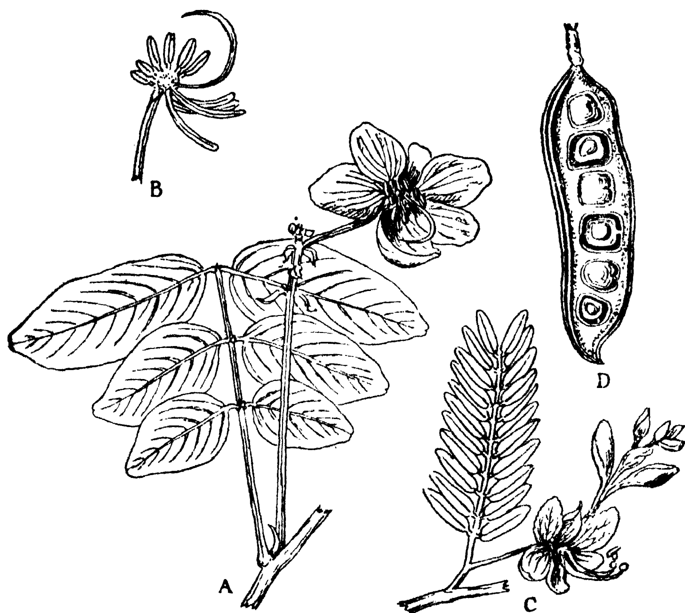


FIG.—105. A, flowering twig of Cassia; B, flower of Cassia, perianth removed; C, inflorescence of Tamarind; D, fruit of Tamarind.

1. The posterior petal is overlapped by the posterior lateral ones, which again in their turn are overlapped by the anterior lateral pair—ascending imbricate aestivation (Cf. descending imbricate in Sweet Pea).
2. Stamens are all free. In Bauhinia, there are only 5 stamens. In Cassia, of the 10 stamens, some are staminodes, and in Tamarindus, only 3, perfect stamens are present.
3. Pistil—as in Papilionaceæ.

Mimoseæ—Common plants are **Acacia arabica, Mimosa-pudica, Albizzia Lebek,** etc.



Fig. 106.—*Acacia arabica. a,* flowering branch; *b,* flower.

In Acacia (Fig. 105) the leaves are evenly two pinnate leaflets, small; and stipules spinescent. The flowers are yellowish. They are in globose axiliary heads. Bracts, usually two. In the flower, observe:—

1. Sepals, 5, 4, or 3, connate in a campanulate shortly toothed calyx.
2. Petals, 5, or 4, exserted, connate below.
3. Stamens—many, exserted, free or shortly connate at the base.
4. Ovary—sessile or stipitate, 2—many ovuled.

In **Mimosa pudica,** note that there are no bracts, and sepals, petals, stamens (normally) are all four in number. Here the fruit is a membraneous flat **disarticulating** lomentum, the one seeded joints separating. In Acacia, the fruit is never disarticulating.

Rosaceæ.—Herbs, shrubs or trees with alternate, stipulate leaves. The apocarpous pistil and numerous stamens arranged in whorls are characteristic of this family. The family is divided into a number of sub-families of which we will consider the important ones.

Potentilleæ—with floral receptacle flat or convex, bearing numerous free carpels which develop into nutlets, drupes or berries. Blackberry (Rubus) and Strawberry (Fragaria) belong to this group. In Rubus note the climbing habit, and the forms of the leaves and stipules.

The leaves vary much in the different sorts of brambles. Observe that where one of the long branches bends down and touches the soil, it is apt to put out adventitious roots, and a new plant is thus formed when the stem connecting it with the parent becomes severed. There is but little difference between this and a stolon, save that the stolon is more regular in its creeping habit and reproduction of new plants.

Note the inflorescence.

In the flowers note—

1. The calyx, its downy, glandular character.
2. The corolla.
3. The andrœcium, of numerous stamens. Specially note the marked perigyny of the flower.

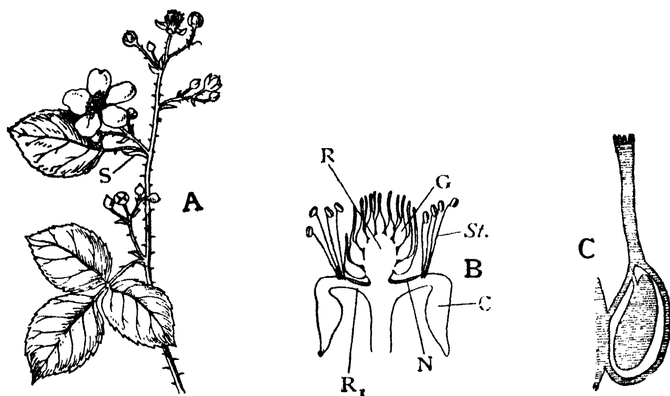


FIG. 107.—Bramble (*Rubus fruticosus*). **A**, Flowering branch; S, stipule. **B**, Flower after petals have fallen; R, receptacle; R_1 expanded part of receptacle ('calyx tube'); N, nectary; C, calyx; *St*, stamens; G, gynæcium. **C**, Carpel containing pendulous anatropous ovule.

4. The honey-secreting disc or nectary.
5. The gynæcium. Polycarpellary superior. The carpels borne on a rather fleshy, peg-like receptacle.

Compare the flower with that of a Buttercup. Save in the perigyny, note the close general resemblance.

6. The fruit, an etærio of drupels. Pick out one of the fruitlets and dissect it. Note—
   (*a*) The skin or epicarp.
   (*b*) The pulp or mesocarp.
   (*c*) The stone or endocarp.
   These three together constitute the pericarp of this fruitlet.

Inside the stone is the seed. Select a **ripe** fruit and dissect out a seed, and observe the absence of albumen—another feature distinct from Ranunculus.

In Fragaria the leaves are palmately compound. Flowers mostly axillary with five bracteoles. Note Floral formula—K (5), C5, A_{∞}, $G_{\underline{\infty}}$.

Pruneæ.—Flowers perigynous, with a single carpel seated on a cup shaped receptacle. Note two ovules. Fruit—a one-seeded drupe. This group includes the Peach **(Prunus persica)** and the Almond **(P. Amygdalus)**.

The Peach is a middle-sized tree with simple lanceolate leaves. Note flowers are sessile, pink in colour and that they appear before the leaves, from scaly buds on previous year's shoots. Floral formula—K(5), C5, A_{∞} $G\underline{1}$.

Roseæ.—Take any species of single rose **(Rosa canina)**. Carefully note the inflorescence of this plant, and observe the reduced character of the bract leaves of the flowering branch. Note the coloured glandular tips at the ends of the teeth of both leaves and stipules.

In the flower observe—

1. The calyx, of five sepals. Note the peculiar outgrowths ending in glands, of some of the sepals. Two are provided with beards on both sides, one with a beard on one side, the other two are destitute of the outgrowths. Take an unopened bud, and correlate these facts with the æstivation of the calyx.
2. The corolla. Note its æstivation in the bud; contrast it with that of the calyx.
3. The perigynous andrœcium. Observe the mode of dehiscence of the anthers.

4. The large disc situated internally to the anthers. This secretes little or no honey.

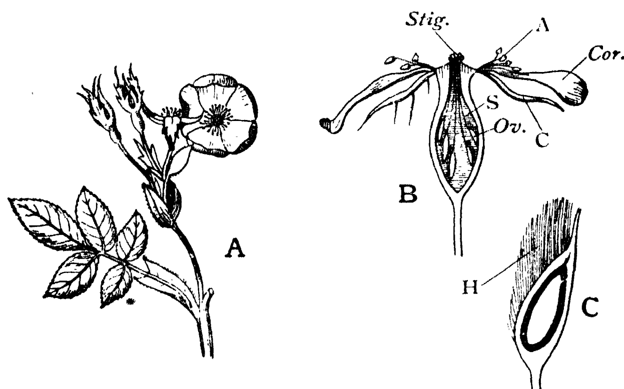


FIG. 108.—Dog-rose (*Rosa canina*). A. Inflorescence. B. C, calyx; *Cor.*, corolla; A, andrœcium; *Ov.*, ovary; S, style; *Stig.*, stigma. C. Section through ovary, showing the position of the anatropous pendulous ovule; H., hairs.

5. The carpels, borne on the base and sides of the hollowed thalamus. Note the hairy character of the carpels, and the long styles with blunt stigmas protruding through the aperture left in the ring-like disc. Dissect a carpel so as to see the position of the ovules. Cut the flower longitudinally, in order to better appreciate the relations of the various parts.
6. The fruit, hairy achenes enclosed in the fleshy red receptacle cup.
7. Floral formula—K(5), C5, A∞, G$\underline{\infty}$.

Pomeæ.—This group is distinguished from the others by its inferior ovary, which usually consists of 5 carpels. Let us take the Pear **(Pyrus communis)** and examine it carefully.

This flower is not very easy to understand. Having noted the short branches (' fruiting spurs ') on which the

flowers are clustered, determine the character of the inflorescence, remembering to look out for the position of the oldest flowers.

In the flower itself make out the following points :—

1. That it is actinomorphic.
2. That it is perigynous.

It is this latter feature which requires special care. Observe the position of the andrœcium, noting how the stamens are packed in the buds. Within the stamens comes the large concave honey-secreting disc, through which, as in the Rose, the styles and stigmas protrude. Note that the latter are mature before the stamens, and that the flower is therefore **Proterogynous.**

Cut the flower across, about halfway down the thickened portion before the calyx, and note the ovary. There are five separate chambers which abut on the central cavity through which the styles pass, and they are enclosed elsewhere by the tissue of which the cup-like outgrowth of the receptacle is made up.

Take some longitudinal sections through the middle of the flower, and observe that the styles spring from about the middle of the side of each chamber, next the central canal of the flower through which all the styles pass. Observe the way in which the anatropous ovules are borne on the placenta.

Compare what you find here with what you have seen in the Rose. The apparent cohesion of the carpel to the cup-like receptacle in the Pear is due to the peculiar way in which the carpel arises on this, so that there is a very broad base, formed on the inner side of the receptacle, which produces the appearance of cohesion. But the position of the style and of the ovule reveals the real state of things, and if you carefully study the gynæcium of the Rose for comparison, you will find the Pear is, after all, not very unintelligible.

The floral formula of the Pear is K (5), C5, A∞, G$\overline{(5)}$.

Cucurbitaceæ—These are climbing shrubs. They climb by means of extra axillary simple or branched tendrils. Flowers, regular, 1-sexual, monœcious or diœcious; usually in panicles, rarely racemose, often solitary.

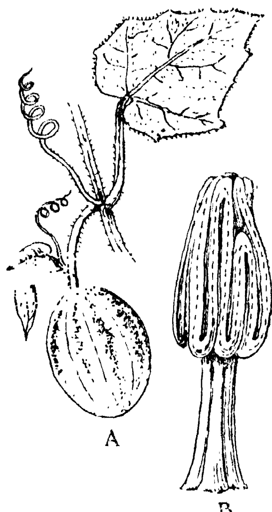


FIG. 109.—*Cucumis melo*. A, fruit; B, sinuous anther.

Examine a **Cucumis Melo** (Melon) first. Note the simple tendril (Cf. gourd-compound tendril). In the flower observe—

1. That they are unisexual, and have 5-united sepals and 5-united petals.
2. The male (staminate) flower has 3-stamens; one 1-celled and two 2-celled; anther cells curved and the connective crested, i.e., produced upwards.
3. The female (pistillate) flower has a tricarpellary pistil with 3-stigmas. Ovules—many, horizontal on three vertical placentas; fruit an ovoid berry.
4. Floral formula—

   In the staminate flower—K (5), C (5), A3.

   In the pistillate flower—K (5), C (5), G $(\underset{\bullet}{3})$.

Other important plants belonging to this family are **Cucumis sativus** (Cucumber), **Lagenaria vulgaris** (Bottle gourd), **Citrullus vulgaris** (Water Melon), **Cucurbita maxima** (Gourd), **Momordica Charantia** (Karala), etc.

Umbelliferæ—Carrot **(Daucus carota).** This common Umbellifer will serve as a type for the greater number of the Indian species of this order (Fig. 110). Observe the 2–4 pinnate leaves with ultimate segments small and narrow; note the sheath at the base of the petioles.

The inflorescence consists of compound umbels. Look for the pinnate bracts and the bracteoles, if present: entire or 3-fid.

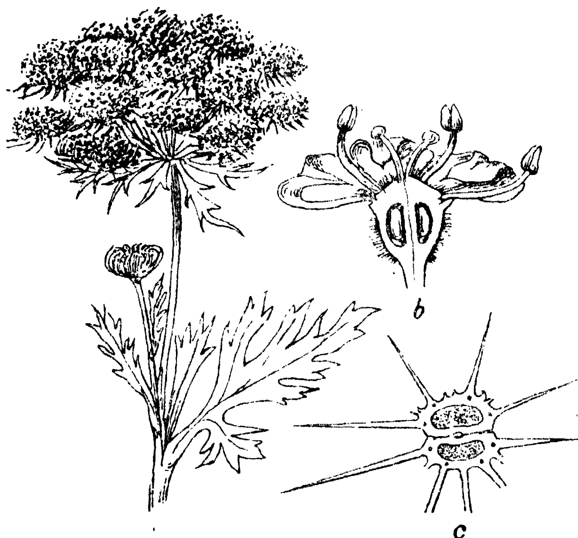


Fig. 110.—*Daucus carota*. *a*, inflorescence ; *b*, section of a flower ; *c*, section of a fruit.

In the flowers note the tendency (chiefly seen in the petals) to zygomorphy on the part of the peripheral flowers of a head. In a single flower observe—

1. The calyx, of five small teeth ; epigynous.
2. The corolla, of five polypetalous petals ; also epigynous. The elongated tip of the petals is sharply incurved.
3. The andrœcium, of five epigynous stamens. Carefully observe the way in which these stamens ripen and rise up, to dehisce and liberate the pollen. Note also that the stamens which have shed their pollen frequently break off the flower.
4. The prominent disc, a circular gland secreting honey.

5. The inferior gynæcium. Note the two styles and stigmas. Carefully note the way in which they mature, and the positions they take up when ready for fertilization. Cut across the ribbed ovary, and note—
   (*a*) That it is bilocular.
   (*b*) That one ovule hangs in each chamber.
   (*c*) In the carpel wall the ridges and furrows and the oil ducts (**vittæ.**)

Cut longitudinal sections of the ovary, and note the pendulous anatropous ovules, and the place of their attachment.

6. The fruit—its form, the arrangement of the vittæ, and the manner in which it splits into two one-seeded parts (**mericarps**), which for some time remain attached to the carpophore. Dissect out the seed, remove the testa, and note the endosperm and the embryo lying ensheathed in it.
7. Floral formula, K(5), C5, A5, G ($\dot{2}$).

Next obtain specimens of Fennel (**Foeniculum vulgare**). It is a tall glabrous herb with compound and repeatedly pinnate leaves. Note, specially—

1. Yellow flowers in compound umbels.
2. The absence of involucre as well as of involucel.
3. Sepals connate in a calyx with entire limbs, and emarginate petals.
4. Fruit, oblong or ellipsoid with eight prominent ridges.

Other Umbelliferæ which should be examined are **Hydrocotyle asiatica, Carum copticum,** and **Coriandrum sativum.**

CHAPTER XXXII

COMPOSITÆ, ASCLEPIADACEÆ, SOLANACEÆ, ACANTHACEÆ, SCROPHULARIACEÆ, LABIATEÆ

Compositæ.—As the first example of Compositæ, we will examine the Sunflower (**Helianthus annuus.** Fig. 111).

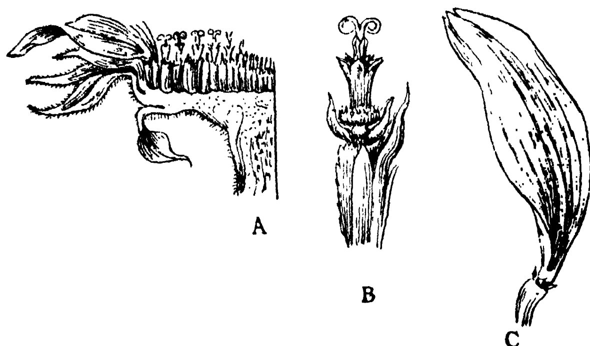


FIG. 111.—*Helianthus annuus.* A, section of a capitulum; B, tubular flower C, ligulate flower.

Observe, in the first place, that the head is a **racemose inflorescence** (Capitulum), and that it contains two kinds of flowers, the outer ones having large strap-shaped coherent petals. These are the florets of the Ray; the inner ones are smaller, and have tubular corollas, and are the florets of the Disc. In the second place, the whole head of flowers is ensheathed by rather coarse (in the Sunflower) green bracts, which are imbricated, and in several rows, forming the **Involucre.**

Examine a floret of the Disc, and observe—

1. That it is sessile on the swollen head of the peduncle, and that it arises in the axil of a small bract. The apparent stalk of the floret is the inferior ovary.

2. The corolla, superior (epigynous) on the ovary, narrowed below and expanded above, where the five teeth indicate that it is made up of five coherent petals (Gamopetalous).
3. Just below this are two scale-like structures which may be regarded as representing the calyx.
4. The andrœcium, of five stamens, epipetalous, with the anthers all joined together (Syngenesious) to form a tube. The anthers dehisce introrsely.
5. Remove the corolla, and observe that the style projects upwards from the top of the ovary ; it passes through the tube formed by the anthers. At its apex it bears the two stigmas. In young flowers, note that these are closed together ; but when, by elongation of the style, they have been pushed out above the anthers, the two lobes divaricate, and curve outwards. Carefully note the hairy brush on the style by which the pollen is swept out of the anther tube when these structures dehisce to let out the pollen. Examine several flowers to find out at what stage in the development this dehiscence occurs, and observe how the pollen is carried out of the tube.

At the base of the style, and around it, the disc-like nectary, which secretes abundant honey.

Cut open the inferior ovary, and note it is unilocular, and that a single anatropous ovule springs up from its base.

Examine a floret of the Ray. Observe—

1. The epigynous corolla, tubular below, and expanded into a strap-shaped ligular structure above. Note the teeth into which it is divided at the end.
2. The calyx is not so apparent as in the ligulate

floret, only appearing as an irregular rim or ridge at the top of the ovary.

3. The andrœcium is altogether absent.
4. The inferior ovary, terminating above in a more or less reduced style. These Ray flowers are sterile.

Now examine a capitulum of the Corn Bluebottle **(Centaurea cyanus)**, or if this be not obtainable, take one of the Black Scabious **(Centaurea seabiosa)**, which bears hard heads of reddish purple flowers.

In the **Centaurea cyanus** observe—

1. The rows of involucral phyllaries which enclose the inflorescence.
2. The bracts of the flowers on the head.
3. The ray florets, all tubular (or infundibuliform) and neuter. They serve only to attract insects.
4. The inner fertile flowers, also tubular, but much smaller than the ray florets. In them note—
   (*a*) The corolla, rising superiorly from the ovary.
   (*b*) The rudimentary pappus, situated just below it.

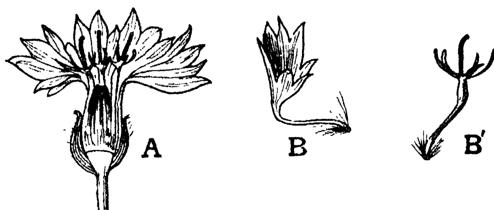


Fig. 112.—Corn Bluebottle (*Centaurea cyanus*). **A.** Section of capitulum. **B.** Sterile floret of the ray. **B′.** Fertile floret of the disc.

   (*c*) The stamens, inserted on the corolla tube. Take a bud about to open; keep it in water till it does so, and then with a bristle touch the filaments of the stamens. A sharp contraction, causing the pulling down of the syngenesious anthers, will result. This

often cannot be seen in plants growing out-of-doors, as they may have been already fully stimulated by insects. Note the dehiscence of the anthers.

(*d*) The gynæcium. The form of the ovary; the style, surrounded by a honey-secreting disc at its base, and at the top, just below the stigma, provided with a brush of hairs. Carefully observe in stimulated flowers the way in which the brush clears out the pollen. The two stigma lobes, which divaricate after the brush has swept out the pollen from the anthers.

Next examine the heads of the Dandelion (**Taraxacum**). Having noted the hollow peduncle, and the milky juice (**Latex**) which exudes from its cut end, observe—

1. The involucre of Phyllaries. Their form, character of their margins, and the number of rows.
2. All the flowers are strap-shaped (**Ligulate**), and are without bracts on the flattened receptacle.
3. The corolla, arising from a platform connected by a thinner column with the ovary wall. Note carefully the form, and also the number of petals (as indicated by the teeth) of the gamopetalous corolla.
4. The pappus of hairs situated just below the corolla.
5. The five syngenesious epipetalous stamens. These protrude above the small tubular part of the corolla.
6. The gynæcium. The ovary, somewhat spiny above, slightly striate; the beak, just below the pappus; the style and stigma. Note especially the way in which the pollen is pushed out of the anthers, and the position taken up by the stigma in fully open flowers.

Examine capitula which are forming fruits, and observe the growth of the pappus, and the lengthening of the beak. Observe the way in which the flowering and fruiting capitula behave in wet weather, and also at night.

Next examine a Sonchus plant (Fig. 113). Any one of the common species may be selected. Having noted the hollow peduncle and the milky juice which exudes from the cut end, and the stalked capitate glands in the



Fig. 113.—*Sonchus oleracea*, inflorescence.

upper portion, note the deeply cut radical leaves, and the difference between them and the much simpler cauline leaves. The segments of the leaves often become spinulose toothed. Note also the flowers in capitula which are terminal, or irregularly arranged in sub-corymbose, umbellate or panicled manner. In each capitulum, observe—

1. Involucre of many seriate bracts.
2. The many florets, all ligulate and yellow in colour.
3. The flat naked receptacle.

In the flower observe—

1. Calyx limb, setose; petals, connate in ligulate corollas, with truncate 5-toothed lamina.
2. Stamens, five, syngenesious; anthers with sagittate base; auricles shortly setaceous, accuminate.
3. Style with slender arms.
4. Cypsella—ovoid, compressed, ribbed; pappus-copious.

Asclepiadaceæ—(Fig. 114). We will take **Calotropis gigantea** (Akanda, Ak, or Mudar) as representing the

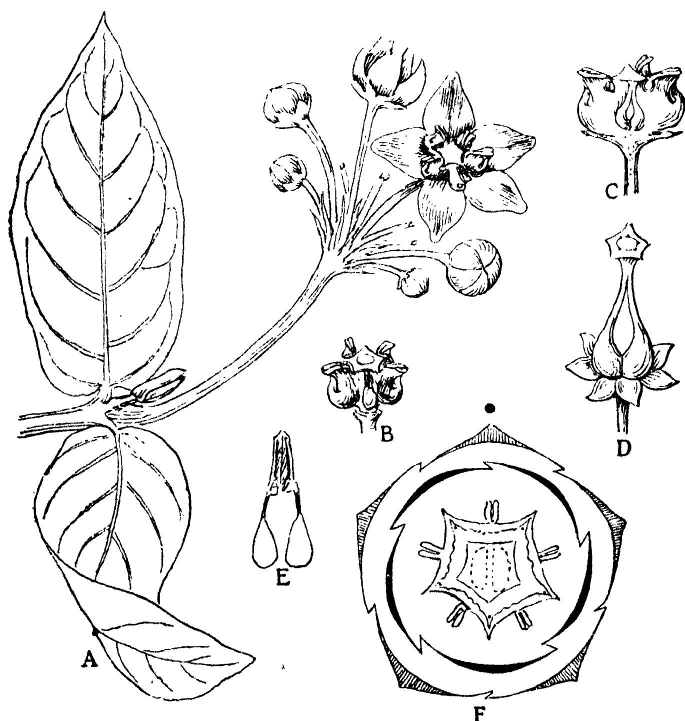


Fig. 114.—*Calotropis gigantea.* A, inflorescence; B flower with sepals and ptaels removed; C, vertical section of flower; D, pistil; E, pollinium; F, floral diagram.

family. This is one of the commonest shrubs of India abounding in milky juice. Observe that the young shoots, leaves, and pedicels are all covered with a soft tomentum. Note the simple, opposite, exstipulate, articulate leaves. Flowers are in umbelliform or sub-racemose cymes. In the flower note—

1. Sepals connate in a 5-partite calyx, glandular at the base within ; lobes, lanceolate.
2. Petals, 5, connate in a campanulate corolla ; corolla lobes spreading.
3. Stamens, 5, adnate near base of corolla tube. Observe the stamens cohering round the pistil, and the 5-lobes alternating with and exterior to the stamens forming the **Corona.** Scales of corona, truncate, hairy. The staminal column **(Gynostemium)** ends in a 5-angled disc. At the centre of each angle, note the hard and black gland **(Corpusculum)** bearing on either side by means of connective **(Caudicle)** a pollen mass **(Pollinium).** Find out, by dissection, that the members of each pair of pollinia belong to different but contiguous anthers.
4. Carpels, 2, distinct ; stigma-depressed, 5-angled.
5. Fruit of two short, thick, accuminate follicles. Seeds comose.
6. Floral formula, K(5), C(5), A(5), $G\underline{2}$.

Another species, **Calotropis procera,** is also quite common. It differs from **C. gigantea** in having corolla lobes erect and scales of corona acute. Species of Asclepias, if found, should also be examined.

Solanaceæ.—Take a branch of the common solanaceous plant, **Solanum nigrum** (Fig. 115) bearing flowers. Note—

The inflorescence, often not obviously connected with a leaf. This is common in plants of this order, and is due to the irregular growth of the stem and leaf respectively, whereby the leaf is often widely

separated from its axillant (inflorescence) branch. Note also the cymose character of the inflorescence.

In the flower observe—

1. The gamopetalous calyx. Its position and the number of its sepals.

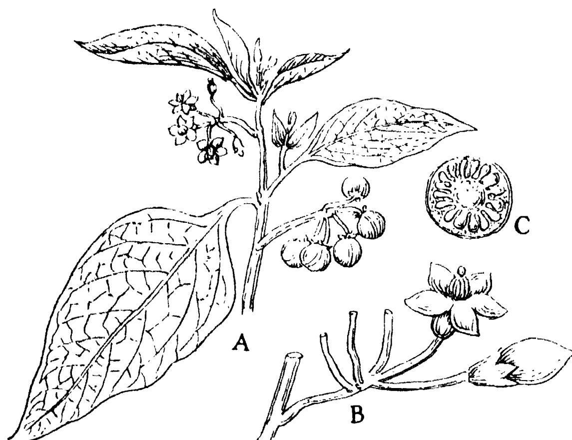


FIG. 115.—*Solanum nigrum*. A, inflorescence; B, a flower and bud; C, section through a fruit.

2. The corolla. Its position, form, and the number of the petals.
3. The andrœcium, five stamens, polyandrous, epipetalous, alternating with the petals. Examine the anthers carefully and note the terminal pore, through which the anther dehisces.
4. The gynæcium. The form of the ovary, style, and stigma, the number of the carpels and loculi, their position with regard to the axis (this requires care, for remember that the inflorescence is cymose, and therefore any

one flower must be considered with reference to the next older one, on the stalk of which it arises as a lateral branch), the placentation.

5. The fruit, noticing the origin of the pulp.
6. The seeds. Are they albuminous or exalbuminous?

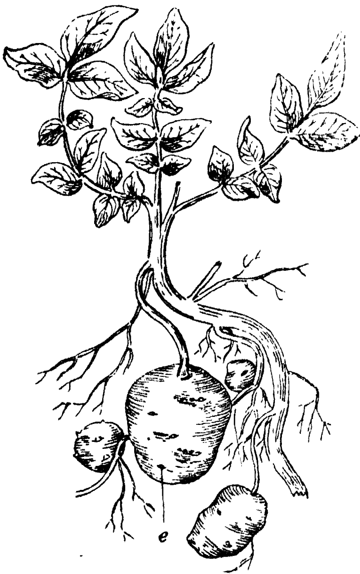


FIG. 116.—A potato plant with tubers. *e*, 'eyes'.

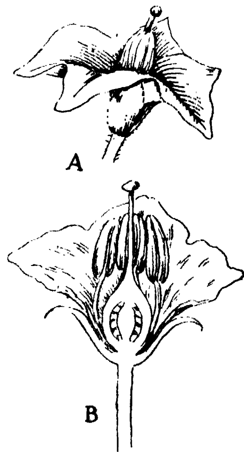


FIG. 117.—*Solanum tuberosum* (potato), A, flower; B, same in section.

Next dig up a flowering plant of Potato—**Solanum tuberosum** and wash carefully. Note, that the shoots in the axils of the lowest leaves, grow under-ground and become tuberous. Make out the 'eyes' which are really vegetative buds. Observe the slightly angular

stem and compare the large flower of this plant with that of **Solanum nigrum.**

Now examine a flower of **Datura stramonium** (Fig. 118) **or Datura Fastuosa. Var. alba.**

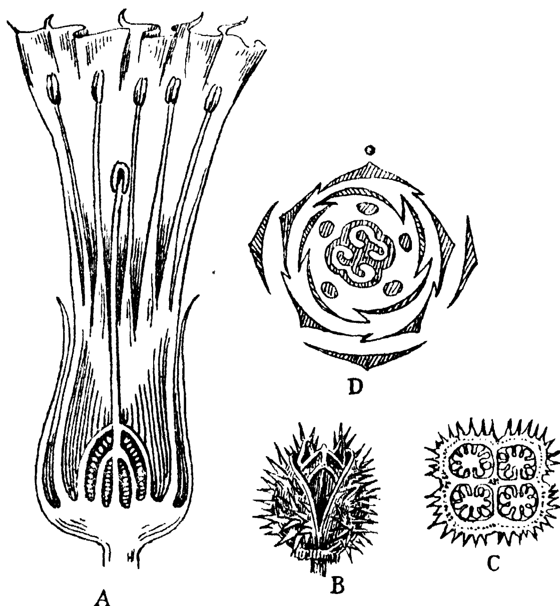


FIG. 118.—*Datura stramonium.* A, flower (section); B, fruit; C, section of a fruit; D, floral diagram.

In the large solitary pedicelled flower, note—

1. Sepals connate in a long tubular, herbaceous, five-toothed calyx.
2. Infundibuliform 5-lobed corolla.
3. Stamens, adnate to near base of corolla tube.
4. Carpels—connate in a spuriously 4-celled ovary.
5. Fruit, an ellipsoid spinescent capsule; capsule deeply 4-valved, almost to the base.

Acanthaceæ.—(Fig. 119). Plants with opposite leaves and irregular flowers. We will first examine any cultivated plant of Justicia. In the flower note—

1. Sepals, 5-4, narrow, slightly connate below.
2. Petals, 5, forming a 2-lipped corolla; upper lip two lobed, lower 3-lobed.



FIG. 119.—A, inflorescence of Justicia; B, inflorescence of *Adhatoda Vasica*; C, floral diagram of Justicia.

3. Stamens, 2, anthers 2-celled.
4. Carpels connate in a 2-celled ovary, ovules two in each. Stigma 2-fid.
5. Fruit—an ovoid or ellipsoid capsule.

Next examine the common **Adhatoda Vasica** (Vasaka,

Arusha, or Adhasa). It is a dense shrub with bracteated spikes ; bracts, herbaceous. Bracteoles, as large as bracts. Flowers—subsessile, several in the axils of opposite bracts, in dense oblong thyrses, at the ends of branches or fascicled in the upper axils.

The extracts of leaves of Vasaka are much used for medicinal purposes.

Another plant Ruellia, a common weed, may also be examined. It is a much branched herb with long internodes and nodes slightly thickened. Note that the flowers have no bracts, though they are generally present in the family.

Scrophulariaceæ.—We will first examine the common **Verbascum Thapsus.** Note the general woolly character of the plant. The form and arrangement of the leaves.

Study the inflorescence. At first sight it resembles a spike, but the flowers do not open acropetally and you will find them distributed with apparent irregularity on the main stem. Determine for yourself the nature of the inflorescence.

In the flower make out the following points :—

1. The æstivation of the parts (best seen in a bud).
2. The form and character (insertion and coherence of parts) of the calyx. Note the position of the odd sepal.
3. The corolla. Specially observe its almost regular form. The number and arrangement of the petals, the colour-markings.
4. The andrœcium. Its epipetalous condition. Pull off the corolla, and note that the stamens are also pulled off with it. Carefully note the number and the relative size of the stamens, specially with reference to the posterior one. Observe the hairy nature of the filaments. [What use can you suggest for these hairs? Watch insects at work on the flowers to find the answer.]

5. The gynæcium. The ovary, style, stigma. How many chambers has the ovary? What is their position? How are the placentas and ovules distributed? Answer these questions by cutting the ovary across, and examining the cut surface with a lens. In order to do this, you will have to remove the corolla. Mind, however, that you remember which is the posterior part of the flower. You can do this by putting a mark on the outside of the calyx. The characters of the ovary are very important as ordinal characters.
6. The fruit and its dehiscence.

Next we will examine the common **Lindenbergia urticifolia.** It is an annual weed found during the rainy season growing on old brick walls. Note the small axillary solitary yellow flowers. In the flowers specially note the five petals connate in a two-lipped corolla; upper lip outermost, 2-fid; lower larger 3-lobed, spreading; throat and lip with a 2-plicate palate. Stamens 4, didynamous. Fruit a two grooved loculicidal capsule.

The annual cold weather weed **Veronica agrestris,** may next be examined and compared with Lindenbergia.

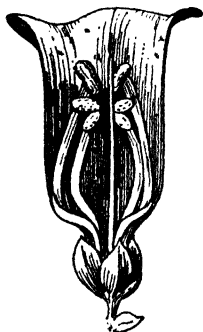


FIG. 120.—Flower of Foxglove, with the corolla opened to show the stamens and style.

Next take the Foxglove (**Digitalis purpurea**). Note its racemose inflorescence, but also that the flowers are all directed to one aspect.

Compare the structure of the flower with the foregoing plants, noting carefully the position of the stamens, and the manner in which the anthers dehisce.

Also study the form of the gynæcium, the ripening and the dehiscence of the fruit.

Labiatæ.—As the first example of this order we will

study **Salvia plebeja** (Bhui Tulsi, Fig. 121). Note the erect herbs with **square stems** (an important character).

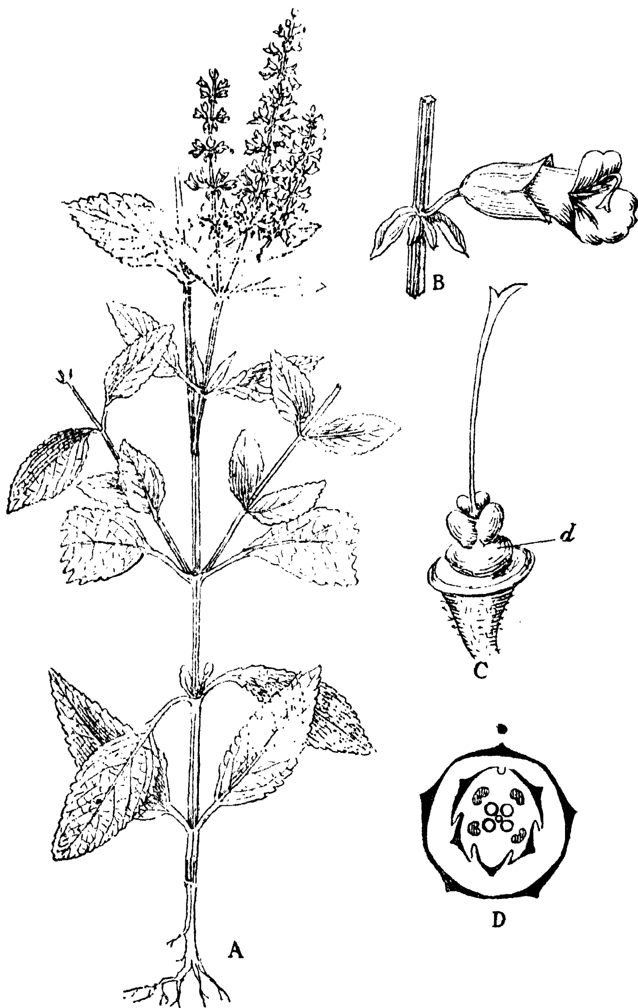


FIG. 121.—A, a flowering plant of *Salvia plebeja* ; B, flower of same; C, flower with the perianth removed ; *d*, disc ; D, floral diagram of *Ocimum sanctum*.

Observe the flowers are usually in racemes of 5–7, flowered, opposite groups. Note that each group is a dichasial cyme at first but later on becomes monochasial.

In the flower observe—

1. Its zygomorphic character.
2. The gamosepalous inferior calyx. The 5, sepals connate in a 2-lipped calyx. Upper lip entire or 3-toothed ; lower 2-fid.
3. The gamopetalous inferior corolla, 5, petals connate in a 2-lipped corolla. The upper lip entire, erect; the lower 3-lobed with lateral lobes spreading.
4. The andrœcium of two stamens; antero-lateral pair; filaments, short; connective elongated with one anther lobe at each end; anterior only fertile. Posterior stamens represented by small staminodes or obsolete.

This plant is specially adopted for insect pollination. The elongated connective is rocking and on being moved by a visiting bee, brings the anthers in contact with the bee which effects cross pollination.

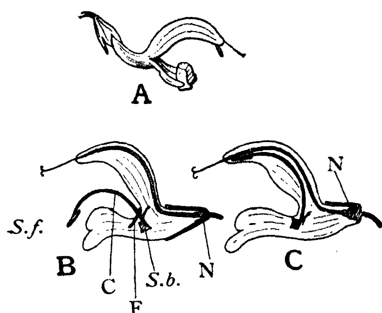


Fig. 122.—Meadow Sage (*Salvia pratensis*). A, Flower. B and C. Longitudinal section of flower ; N, nectary ; F, filament ; C, connective ; *S.b.*, barren anther-lobe ; *S.f.*, fertile anther-lobe.

5. The superior gynæcium. Apparently of four carpels.

Cut transverse sections of young buds so as to see the arrangement of the carpels. You will find that there are really **two** carpels, but that each one of them is, later on, divided by a partition into two chambers, each containing an ovule. Observe the position of the style, also the form of the stigma. Examine and compare

the form and position of the stigmas in flowers of various ages. Note also the nectary, a fleshy expansion of the base of the ovary, especially on the anterior surface.

6. The fruit, splitting into four nutlets. Compare it with the fruit of a Geranium or a Cow Parsnip with respect to its schizogenous character.

Now examine one of the **Ocimums (O. sanctum).** Note the labiate corolla with upper broad and 4-lobed lip, and a narrow lower lip, curved downwards. Remove the corolla carefully and note the four epipetalous, didynamous **perfect** stamens. Pistil as in the last specimen. The fruit consists of four nutlets, schizocarpic. Draw a floral diagram (Fig. 121,D).

Floral formula, K (5), C (5), A 4, G $(\underline{2})$.

CHAPTER XXXIII

SUB-CLASS INCOMPLETÆ

EUPHORBIACEÆ, URTICACEÆ

Euphorbiaceæ—(Fig. 123). Trees, shrubs or herbs; often with milky or watery juice. Flowers, uni-sexual. Ovary, free; usually 3-celled, with just one or two ovules



FIG. 123.—*a*, inflorescence of Ricinus; *b*, inflorescence of Euphorbia; *c*, female flower of Ricinus; *d*, male flower of Ricinus; *e*, branching stamens of Ricinus.

in each cell. We will first examine the Common Castor-Oil Plant (**Ricinus communis**). Observe the large alternate, peltate, palmately-lobed leaves. Note that it bears terminal racemes or panicles of simple or compound

dichasial cymes. Flowers, unisexual; the female flowers being above. In the staminate flower, note the 5-partite calyx, absence of corolla and numerous stamens. Observe that the filaments of stamens are branched repeatedly, and that the ultimate ends bear half anthers. In the pistillate flower, the 5-partite calyx is usually coloured. Corolla absent. Pistil, 3-carpellary, syncarpous, superior. Ovary, trilocular, with axile placentation. One ovule in each loculus. Note that the three styles are forked into six stigmas. Fruit a schizocarp, with dehiscent carpels.

The dried seeds yield castor oil.

Any species of Euphorbia may next be examined. Note that the flowers are usually combined in an inflorescence of many male florets, surrounding a solitary female within a small 4-5, lobed regular perianth-like involucre. Perianth is absent or represented by minute scales. Fruit a capsule.

Urticaceæ.—Let us first examine the Mulberry (**Morus alba**). It is a deciduous tree with alternate simple stipulate leaves. It is largely cultivated for the rearing of the silk worms. The fruits are also edible. Observe the flowers are in catkins. Flowers are unisexual, monœcious or diœcious. Staminate flowers—P4, A4. Pistilate flowers—P 4, G $\underline{(2)}$. Ovary uni-locular with one ovule. Fruit a **Sorosis** consisting of a large number of one-seeded achenes each enclosed within the fleshy perianth.

Next examine the edible fig (**Ficus carica**. Fig. 124). Note the inflorescences are hollow pitcher shaped structures, with a small opening, bearing flowers which are closely crowded on the inner surface. The male flowers have three stamens. Some of the female flowers become gall flowers, due to development caused by the laying of insect eggs. The gall flowers do not mature. The

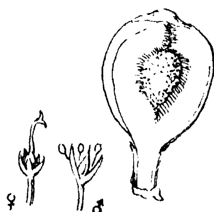


Fig. 124.—*Ficus carica.*

sweet edible portion of the fig is developed from the hollowed axis of the inflorescences. The peepul **(Ficus religiosa)** and the Banyan **(Ficus bengalensis)** should also be examined. Observe the large deciduous stipules which leave ring like scars at the base of the leaves. In Banyan specially observe the adventitious roots given off freely from the branches.

Indian Hemp or Bhang **(Cannabis sativa)** is another example of this family. Note the palmately compound and stipulate leaves. Flowers, small, diœcious. Males in axillary panicled cymes. Females in axillary racemes. The female flowers with hyaline perianth embrace the base of the ovary which is enclosed within the embracing bract. Ovary of two carpels, unilocular. The fruit is achenial.

Only the female plant is cultivated. It is a prohibited plant.

CHAPTER XXXIV

MONOCOTYLEDONS. SUB-CLASS PETALOIDEÆ, LILIACEÆ, AMARYLLIDACEÆ, IRIDACEÆ, SCITAMINEÆ

MONOCOTYLEDONS are distinguished from Dicotyledons not only in the number of their cotyledons, the venation of their leaves, and the internal structure of their stems, but also in their flowers.

Commonly the floral whorls contain three members in each whorl, and typically there is a whorl of three sepals, a similar one of three petals. These are often grouped together as perianth, because of the frequent similarity of form and colour which subsists between the sepals and petals. But it is usually easy to distinguish between them in position. Then typically follow two whorls of stamens, also three in each whorl; and lastly, a whorl of three carpels, which are often joined to form a syncarpous ovary.

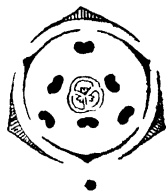


FIG. 125.—Floral diagram of a typical monocot. flower.

But these normal arrangements and proportions may be obscured in various ways. Some or all of the members of a whorl may be absent, or the members in a whorl may be increased. And furthermore the normal arrangements may be obscured by zygomorphic replacing radial symmetry.

Liliaceæ.—The flowers of this order have often brightly coloured sepals and petals. The corolla and the calyx, as they are often alike in colour and form, are frequently spoken of as the perianth. Perianth usually 6-merous in 2-series. Flowers hermaphrodite rarely by abortion

1-sexual as in **Smilax**. Stamens 6, rarely 3, or fewer. Carpels three, connate in a superior three-celled ovary. Fig. 126B shows the floral diagram of a typical Liliaceous plant. Liliaceæ resemble very much the Amaryllis family, but is distinguished by its superior ovary.

Now examine a flowering herb of **Asphodelous tenuifolius.** Observe the short underground stem, bearing adventitious roots at the lower end. Note the simple exstipulate, cylindrical and erect radical leaves. Floral formula $P\ (3 + 3),\ A\ 3 + 3,\ G\ (\underline{3})$.

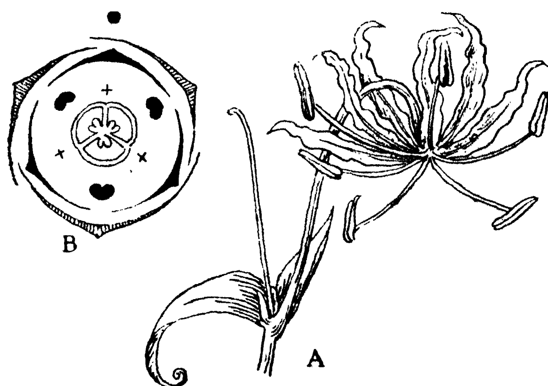


Fig. 126.—A, *Gloriosa superba*; B, floral diagram of a typical Liliaceous flower.

Next examine a flowering plant of **Gloriosa superba** (Fig. 126A). Note the leafy climbing stem. Leaves broad with tendril-like tips. Observe the large showy, axillary, solitary flower with pedicel reflexed. Note that in the bud state, the flowers are drooping with the perianth folded over the stamens and the pistil. In the open flowers, mark that the perianth lobes curl upwards, exposing the stamens and the pistil.

Gloriosa as well as Yucca are specially adapted for insect pollination.

Amaryllidaceæ—(Fig. 126C). Examine a plant of **Crinum asiaticum,** in flower. Note the large bulbous herb with long smooth radical leaves and large umbels of regular white flowers. Observe that the bulb is often prolonged above the surface of the ground so as to resemble a short trunk. In the flower, observe—

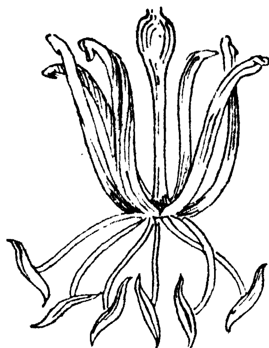


Fig. 126C.—*Crinum Asiaticum.*

1. Perianth of 6, leaves, gamophyllous, superior.
2. Stamens, 6, hexandrous, epiphyllous.
3. Pistil of 3—carpels, syncarpous, inferior, connate in a 3-celled ovary, with many ovules in each loculus. Note the very small sub-capitate stigma.

Floral formula—P (6), A6, G $(\overline{3})$.

Iridaceæ.—Crocus. Dig up a flowering plant of Crocus. Note the external character of the corm, repeating the study of this part of the plant.

Note the brown scales clothing it, and the sheathing scale leaves on the lower part of the ascending leafy portion of the plant. Peel these off, and note the position of the foliage leaves which succeed them. Note the thin scale leaves which occur on the flowering axis. There may be several flowers on a corm; carefully ascertain their positions with regard to the leaves on the old corm.

In the flower note the following points :—

1. The long perianth tube inserted just above the ovary. There are six perianth leaves—three inner and three outer—but all combined into a common tube below.
2. The three stamens. Note their insertion on the

perianth tube, and the whorl of (three) perianth leaves to which they are opposite.

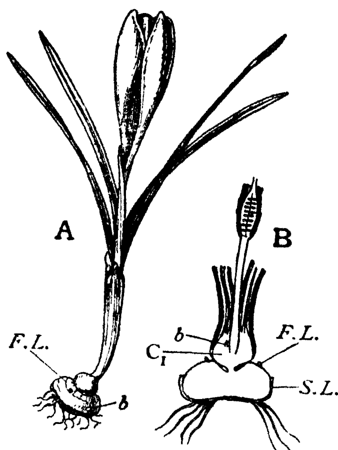


FIG. 127—Crocus. **A**. Flower and young corm on last year's corm (i.e. on the corm formed last year). *F.L.*, bases of foliage leaves; *b*, buds. **B**. Section of a corm when the fruit is forming. C_1, the corm of the following year; *b*, the flowering shoot of the following years.

3. The gynæcium. Observe the three flattened stigmas and the long style. Cut the ovary across in order to see the number of loculi and the character of the placentation.
4. Some weeks after the flowers are over the fruits will appear above ground. The stalk elongates for this purpose. Note the mode of dehiscence.

Freesia.—Another plant very commonly cultivated. Dig up a plant when in flower. Note the **Corm.** Near the growing apex observe the leaves. In the lower portion of the leaf the two sides are approximated **(Equitant)** so as to clasp the next younger leaf. Note that the inflorescence is a one-sided raceme. Observe the flowering axis is bent at right angles after the formation of the first flower. Note the flowers are laterally situated, and that each flower has got to itself one bract and a two-keeled bracteole. In the flower, observe—

1. The superior perianth, gamophyllous, tubular six-fid.
2. The andrœcium of 3-stamens, epiphyllous, opposite the outer leaves of the perianth.

3. The gynæcium—observe the 3-carpellary, syncarpous pistil. Ovary inferior. Note the three stigmas, each deeply divided into two. Ovary 3-locular with axile placentation containing two rows of ovules within each loculus.
4. Floral formula—P(6), A3, $G(\overline{3})$.

Scitamineæ.—Herbs with irregular flowers. Androecium greatly reduced. Some of the stamens are represented by staminodes, resembling petals. These plants have frequently a pseudo stem of convolute leaf-sheaths. It is a large family and is divided into three sub-families, viz., Musaceæ, Zingiberaceæ, and Cannaceæ or Marantaceæ.

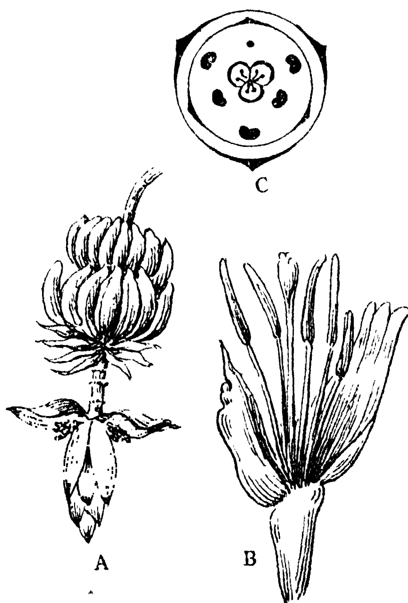


FIG. 128.—Musa. A, inflorescence; B, flower; C, floral diagram.

Musaceæ.—(Fig. 128). Examine **Musa sapientum** (Banana). Note the underground stem **(Rhizome)** and the very large

leaves with sheathing petioles, which form a spurious stem.

Observe the flowers in spikes with large spathaceous red bracts. The flowers at the base are female and those near the apex are male; the central ones being hermaphrodites. Stamens, five, the sixth one being either absent or represented by a staminode. Pistil, 3-carpellary; syncarpous, inferior. Ovary-trilocular. In the edible varieties of Banana, the ovules do not ripen into seeds.

Zingiberaceæ.—(Fig. 129B) **Zingiber officinale** (Ginger). Note the flattened branched rhizome. The main shoot is continued by the growth of the axillary buds on the lower surface. Leaves 2-ranked. Flowers in spike usually radical, bright coloured. Bracts persistent, usually one flowered. Perianth 2-seriate, superior,

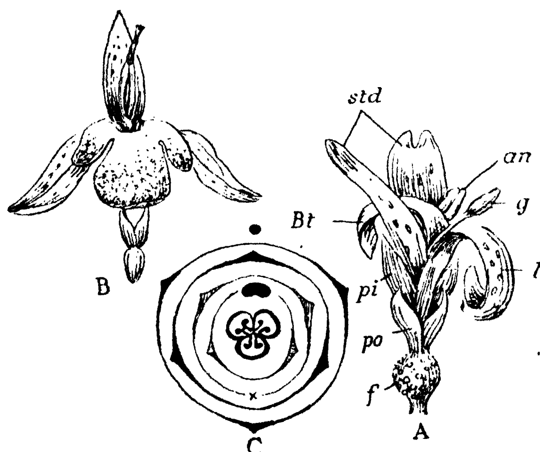


Fig. 129.—A, Conna; *f*, inferior ovary; *po*, outer perianth; *pi*, inner perianth; *Bt*, fertile stamen, with antheridia (*an*); *l*, lavellum; *g*; style; *std*, staminodia; B, flower of ginger (*Zinziber officinale*); C, floral diagram of Zinziber.

outer segments, 3, calycine; inner, 3-petaloid. Stamens 1-perfect; filament, short; anther 2-celled; carpels 3,

connate in a 3-celled ovary. Ovules, many superposed ; axile placentation. Seeds, large, globose arillate.

The dried rhizomes yield the ginger. Other important plants are Turmeric **(Curcuma longa)**, and Cardamom **(Amomum aromaticum)**.

Cannaceæ or Marantaceæ.—(Fig. 129A). Indian Shot **(Canna indica)** is cultivated for its showy flowers. A tall herb with simple leafy stem and perennial root stock. Note specially that the single perfect stamen has a petaloid filament. Only one anther lobe is fertile, the other being petaloid. Carpels—three, connate in a 3-celled ovary.

Another important plant is **Maranta arundinacea.** The bulbs yield starch, which is the arrowroot of commerce.

CHAPTER XXXV

SUB-CLASS SPADICIFLORÆ—PALMACEÆ, AND SUB-CLASS GLUMIFERÆ—GRAMINACEÆ AND CYPERACEÆ

Palmaceæ.—(Fig. 130). Cocoanut Palm **(Cocos nucifera)** is a tall, unbranched tree, with a crown of large pinnatisect leaves. Flowers, unsymmetric on simply panicled spadices. The individual flowers are unisexual. The male flower consists of P3+3, A3+3 and the female flower, P3+3, G (3). Observe that the scattered female flowers are often between two males near the bases of the spadix, whereas there are only close set male flowers above. Fruit—a fibrous, drupe with a single massive seed. Endocarp, hard with three basal eyes,—the remains of the three ovarian walls.

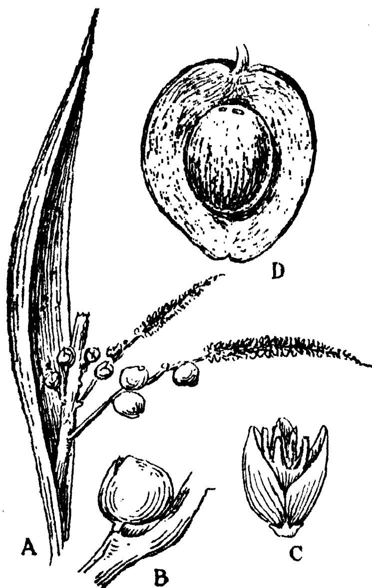


FIG. 130.—Cocoanut (*Cocos nucifera*). A. Inflorescence. B. Female flower. C. Male flower. D. Fruit.

Next examine the common Date Palm **(Phoenix sylvestris)**. Observe the crown of large pinnate leaves with the ends of pinnæ transformed into spines. Inflorescence much branched and enclosed in a spathe. Individual flowers unisexual. Here their distribution is

diœcious. Male flower, P3+3, A3+3; female flower P3+3, G3. The pistil is tricarpellary, apocarpous; but ultimately only one carpel develops. Note that the fruit consists of a thin crustaceous epicarp, a fleshy mesocarp and a thin membraneous endocarp enclosing a single stony seed.

Other important plants belonging to this family are the Betel Palm (**Areca**), Cane (**Calamus**), Palmyra Palm (**Borassus**), Sago palm (**Sagus**), etc. The saccharine juices, of Phoenix, Borassus, Cocos, and other genera are collected for fermentation or boiled down to sugar.

Graminaceæ.—(Fig. 131) The grass family. This is one of the largest and universally distributed families. It includes many plants of great economic importance, viz., Rice, Wheat, Barley, Oats, Maize, Millets, Rye, etc. Take the common flowering Dhoob grass (**Cynodon dactylon**); note the underground rhizome and the trailing stem; or examine the flower of Oat (**Avena sativa**) or of Rice (**Oryza**), or of Wheat (**Triticum vulgare**), or of Barley (**Hordeum vulgare**). In the Dhoob grass, note the knots or nodes of the stem, and observe how the lower part of the leaf sheathes the stem. Pull off a leaf, and note that there is an obvious separation of the leaf into sheath and blade. Look for the thin rather acute **Ligule** which is situated at this spot. [The shape of these ligules, which are exceedingly common in grasses, is very characteristic

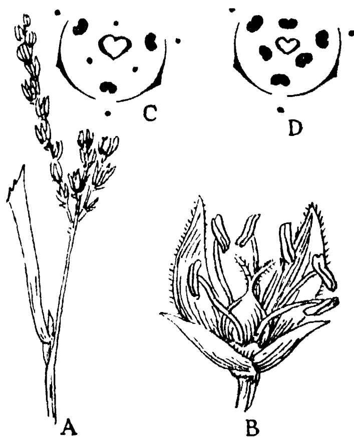


Fig. 131—*Oryza sativa* (Rice), a panicle (**A**), and a single flower (**B**.) **C**. Floral diagram of Oat and **D**. Floral diagram of rice.

for any particular species, and it should always be examined.]

The stem terminates in a paniculate inflorescence.

The flowers are very difficult to study unless they are actually open. Pick off a spikelet in which the flowers are open, and with the aid of a lens and needles make out the following points :—

1. Each spikelet consists of about six or seven flowers.
2. Starting from the base of the spikelet, you will first pick off two empty bracts—the glumes. Next you come to a bract in the axil of which is a flower. This bract is the **Outer Pale** (sometimes also termed the **Flowering Glume**), and it has five ribs running up in it. Opposite to this, at the back of the flower, is the **Inner Pale**, membranous, with two marginal ribs. This inner pale arises on the posterior side of the short flower-stalk, and really represents a bracteole or prophyll. On the anterior side of the flower, just inside the outer pale, note the two **Lodicules**, small membranous scales. These swell up when the flower opens, and, indeed, are the active agents in forcing the pales apart, thus exposing the essential organs of the flower.
3. Next examine the andrœcium, of three stamens, paying special attention to the anthers.
4. Inside of all is the gynæcium, with unilocular ovary and two styles crowned with two feathery stigmas [feathery stigmas are characteristic of grasses]. Note the **single ovule.**
5. As soon as the flower is over, note that the pales close up again.
6. In the ripe fruit observe that the lower pale adheres to the achene (here sometimes termed a caryopsis).

In the panicle of the Rice flowers, specially note spikelets 1-flowered, pedicillate and six stamens (Fig. 131,B, D).

In Maize (**Zea Mays**, note) the plants are monœcious. The male flowers are in terminal panicled racemes, the female flowers, sessile in lateral erect spikes.

Cyperaceæ.—(Fig. 132). It is a large family. Note the grass-like plant with triangular solid stem with closed leaf-sheaths. Examine any species of Cyperus.

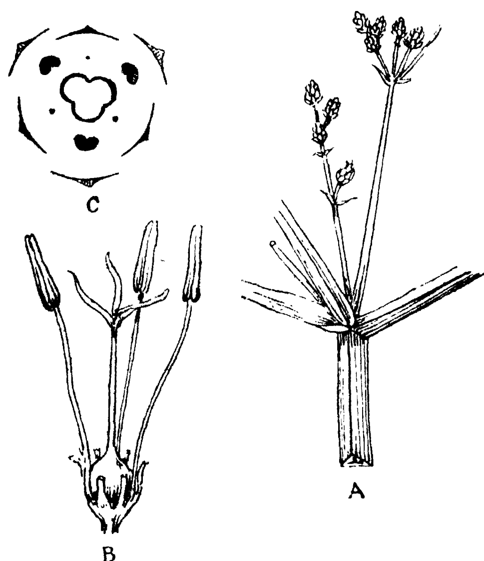


Fig. 132,—Cyperus. A, inflorescence; B, flower; C, floral diagram.

Note the distichous spikelets of hermaphrodite flowers, borne singly, in the axils of imbricating glumes.

Pistil of 3-carpels, syncarpous, superior; stamens, triandrous and perianth nil.

In the common Scirpus, the flowers are also hermaphrodite, but in Genus Carex, it is monœcious and flowers are naked and unisexual.

CHAPTER XXXVI

GYMNOSPERMS. CYCADACEÆ, CONIFERÆ, GNETACEÆ

Gymnosperms.—These plants differ in many ways from the angiosperms, which compose the greater number of the flowering plants. In the angiosperms we have seen that the ovules are enclosed in a case, but in the gymnosperms the ovules are naked, being without any covering. The internal structure of the stem and the root, though very similar to that of the Dicotyledons, differs in having the vessels replaced by tracheids. Bordered pits are very prominent and the resin ducts are present abundantly both in the wood and the cortex. This group is divided into three important families, viz., the Cycadaceæ, the Coniferæ, and the Gnetaceæ of which we will briefly study a few types which are easily accessible.

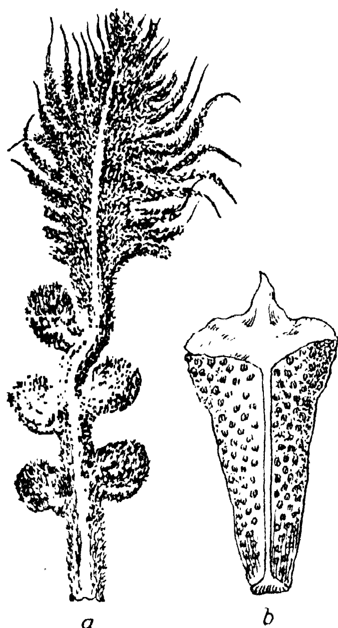


FIG. 133.—*a*, carpellary leaf of *Cycas revoluta*; *b*, male flower of *Cycas circinalis*.

Cycadaceæ.—(Fig. 133). We shall first examine the commonly cultivated plant **Cycas revoluta.** Note the thick short stem with a crown of leaves at the top like the Palms. Leaves are of two kinds. Note the large pinnate, green foliage leaves, often spiny, and the small pointed and woolly scale leaves which protect the growing point. In this plant the normal

pinnæ have revolute margins, hence the name **Cycas revoluta.** In **Cycas circinalis** the leaflets when young are circinately folded as in the ferns.

• Examine transverse sections of the stem and the root. Bead-like cells of an alga **(Nostoc)**, may be seen in the sections of the root.

Now examine the reproductive parts. Cycas is a diœcious plant ; in the male plant numerous microsporophylls are arranged spirally round an elongated axis. Note the numerous sporangia, often in groups borne on the abaxial surface. The female flowers in Cycas occupy the apex of the stem, forming a cone through which the apex of the stem continues to grow and produces foliage leaves later on. It consists of a number of megasporophylls. Each sporophyll consists of a densely woolly and brown pinnate leaf, the lower pinnæ of which are replaced by ovules (megasporangia).

In this country the plants of **Cycas revoluta** cultivated in the gardens are all female plants and they are propagated vegetatively by buds from older plants.

Coniferæ.—(Fig. 134). These are branching trees with simple, usually evergreen leaves. Let us examine the Chir Pine **(Pinus longifolia)**, a tree of the Himalaya, but a common species in the gardens of the plains.

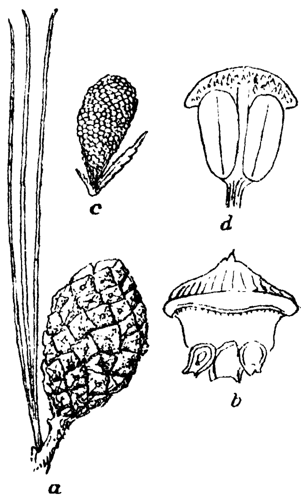


FIG. 134.—*a*, female cone of pine ; *b*, ovuliferous scale ; *c*, male cone of pine ; *d*, scale bearing microsporangia.

Observe the structure and the distribution of the leaves, and note the distinction between the acicular (needle-shaped) foliage leaves and the flattened bud scale leaves.

Note specially that the needle-shaped leaves are borne in clusters of three.

Cut a transverse section of the leaf and note the triangular nature owing to the three leaves being packed together in the bud.

Note that the cluster of the three leaves are borne on a very short **branch** which arises on the main stem in the axil of a scale leaf. These shortened branches are termed **Foliar Spurs.** Note that this short branch first bears a number of scale leaves, and finally produces the two or more foliage leaves proper to the respective species.

In an older tree you will find the flowers. These are of two kinds, male and female and both are arranged as cones. First examine the male cone ; observe that—

1. The male flowers are formed in clusters at the base of the shoots unfolding in the current year and that they replace the lower foliar spurs.
2. That the male cone or flower, first produces on its axis a few green though reduced leaves.
3. Higher up a large number of stamens, each with two pollen sacs occur, and that the pollen sacs are borne on the under surface of the stamens.

In the female flower, observe—

1. That the cones occur at the ends of the young branches. The cones take two to three years to mature their seeds.
2. That the cones consist of an axis bearing scaly appendages. The lower scales are small and simple in form ; they are true leaves.
3. Following on these, the scales are more complex. They are very small (bract scales), but in their axil arises a stout fleshy body, which is known as the **Ovuliferous scale**, the smaller scale being the true leaf.

4. Upon the ovuliferous scale two ovules are situated, near the base, and they are not contained in an ovary, but are simply exposed upon the scale. Their micropyles point downwards.

In a mature cone observe that—

1. The outer (bract) scales are hardly distinguishable, but the ovuliferous scale has grown largely and now bears the two ripe seeds.
2. A flat plate of tissue becomes scaled off the face of each of the two halves of the upper surface of the ovuliferous scale, and is attached to the seed. When this latter is shed, the plate of tissue serves as a wing to enable the seed to float to considerable distances in the air before reaching the ground.

Gnetaceæ.—This is represented in India by the genus Gnetum in the south, and the genus Ephedra in the Himalaya.

The Gnetums are climbing shrubs with jointed stems. The leaves are entire, opposite. The plants bear axillary spikes of verticillate monœcious flowers.

The Ephedra are leafless and much branched shrubs. They, like all Gymnospermous plants, are anemophyllous.

The Gymnosperms bear large quantities of pollen grains which are specially adapted for wind transport, being light and dry, and often having bladder-like appendages.

PART V

EXAMPLES OF NATURAL ORDERS OF CRYPTOGAMS

CHAPTER XXXVII

THALLOPHYTA—ALGÆ, FUNGI, LICHEN

IN the preceding chapters, we dealt with the seed plants or the Phanerogams. We now turn to consider the spore plants or the Cryptogams. These have been divided into three principal groups, viz., the Thallophyta, the Bryophyta and the Pteridophyta. The thallophyta includes a great variety of plants, consisting of single cells, filaments, or more or less branched thallus. They reproduce both sexually and asexually, but there is often no regular alternation of generations. The bryophyta and the pteridophyta are grouped together as Archegoniates and have regular alternation of generations. The bryophytes have either no vascular system or only a rudimentary one. They possess no true roots like the pteridophytes, though there is segmentation into stems and leaves, and root-like structures are present which are commonly called rhizoids.

Thallophyta.—This constitutes the lowest group of plants. The members of this group consist either of single cells, or they may be multicellular, and exhibit more or less considerable differentiation into tissues. Thallophytes are usually sub-divided into algæ, fungi and the lichens. The algæ are mostly aquatic. They possess chlorophyll pigments, prepare their own food and live independently. The fungi on the other hand lack chloroplasts and are

therefore unable to prepare their own food from simple substances, as do the green plants. The lichens afford an instance of symbiosis of algæ and fungi.

The **Bacteria** (Fig. 135) which are the simplest of thallophytes occupy an isolated position. They are devoid of chlorophyll and hence cannot manufacture their own food materials. They live either as parasites or as saprophytes. Plague, cholera, typhoid fever, tuberculosis, malaria, Kala-Azar, and many other dangerous diseases are due to bacterial infection. They are present everywhere in air, water, soil, bodies of dead or living plants or animals. They are unicellular or filamentous, and are commonly extremely minute organisms.

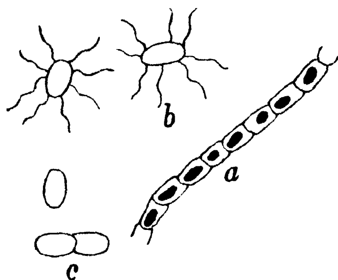


FIG. 135.—Bacteria. *a*, spores inside the cells (endospores); *b*, cells with flagella (motile); *c*, non-motile cells.

Reproduction takes place by fission or partition into two. The cell consists of a protoplasmic body usually colourless and surrounded by a thin membrane. Sometimes they are coloured. Asexual spores or **Endospores** are formed inside the cells, by the inner portion of the protoplasm contracting from the peripheral. The endospore surrounds itself with a wall and may ultimately come out of the mother cell when the spore is ripe.

Many bacteria are motile and they perform their movement by means of cilia which are distributed, either all over the body or come out from localized points. The Hay Bacillus (**Bacillus subtilis**) may easily be obtained in hay decoction. The cells vary greatly, some are non-motile, without cilia and often form intertwined chains of cells, but motile stages also occur.

Most of the bacteria are **Aerobic,** i.e., require oxygen for their respiration. But there are others which can live without oxygen and they are called **Anærobic.**

ALGÆ

We will consider the algæ now. These are classified according to the colour of the cells, viz., **Cyanophyceæ** (Blue-green), **Chlorophyceæ** (Green), **Phæophyceæ** (Brown), and **Rhodophyceæ** (Red).

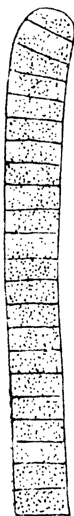


FIG. 136.—Oscillaria filament, top portion.

A very common example of the blue green algæ, is **Oscillaria** (Fig. 136). It is a filamentous form and occurs everywhere in water or in damp places. It consists of similar flattened cells, each with a peripheral chromatophore. The filaments are covered with thick sheaths. When the individual cells become free, they develop into new filaments. The Cyanophyceæ are by many grouped together with the bacteria as **Schizophyta** or fission plants, as members of both reproduce by means of fission or partition.

Chlorophyceæ.—This group is characterized by the presence of chloroplasts which are of a pure green colour and frequently contain **Pyrenoids.** The pyrenoids consist of a central crystalloidal portion of protein which is often surrounded by a starchy envelope.

Some forms like Chlamydomonas or Hæmatococcus consist of free swimming cells. In **Chlamydomonas** the cell membrane is closely applied to the protoplast, and two cilia and a red eye-spot are present at the anterior end. **Pleurococcus** which forms green patches on moist bricks and flower pots, etc., live either singly or in groups of two, four, or more cells. In **Volvox,** the colony looks like a single individual and it consists of a large number of cells connected by fine processes. **Spirogyra** (Fig. 137) is a filamentous form, and is one of the commonest algæ of the fresh water stagnant

ponds. They have a mucilagenous coat and hence are slimy to touch. They form beautiful free floating masses.

Get specimens of Spirogyra and mount a small bit in water and examine under the microscope. Note—

1. That the filaments are unbranched.
2. That the green colour is due to the spiral bands of chloroplasts inside the cells.

Now treat the preparation with a drop of Iodine and note—

(1) the presence of a bright yellow nucleus; observe that the nucleus, contained in a thin skin of protoplasm, is suspended in the vacuole, being connected with the parietal layer by means of cytoplasmic strands;

(2) the pyrenoids embedded in the chloroplasts.

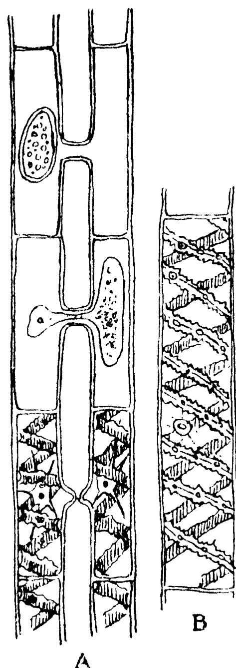


FIG 137.--Spirogyra. A. Conjugating filaments. B. A single cell showing nucleus and band-shaped chloroplasts.

Next procure some conjugating filaments and note they are usually more coarse and dirty looking than are the ordinary vegetative filaments. Reproduction takes place by means of conjugation, during which lateral processes from the cells of the adjacent filaments are developed. When processes from two opposite cells meet together, their walls become absorbed at the point of contact, and the contents of one cell passes through the canal thus formed, into the opposite cell. The protoplasm and the nuclei now fuse together, resulting in a **Zygospore** which becomes invested with

a thick wall. Sometimes the zygote is formed midway in the conjugating tube. The zygote on germination forms a tubular cell first, which later by cell division forms the filament.

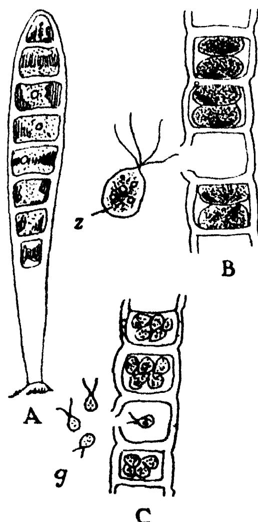


FIG. 138.—Ulothrix. A. Young filament. B. Filament with escaping zoospore (z). C. Filament with gametes (g), escaping.

Ulothrix.—(Fig. 138). It is also a filamentous, fresh-water alga, but is not a free floating form, being attached to the substratum by their basal cells. These filaments are also unbranched like the Spirogyra. Examine a filament under the microscope and note that

(1) the basal or rhizoidal cells are colourless and the filaments consist of rows of short cells.

(2) Each cell has got a band-shaped chloroplast, and that the terminal cell is rounded at its free end.

Treat the filaments with Iodine and bring out the presence of pyrenoids and starch in the cell.

Asexual reproduction takes place by means of 4-ciliated swarm spores, which escape by means of a lateral opening formed by the absorption of the wall. These give rise to new filaments. Sexual swarm spores are formed in large numbers inside the cells. These are bi-ciliated, and smaller than the zoospores (swarm spores), otherwise they are similar. When two bi-ciliated swarm spores or gametes meet together, they fuse, forming zygote. The zygote on germination gives rise to unicellular plants which develop zoospores. In Ulothrix, the gametes from the same filament do not fuse together (diœcious).

Vaucheria (Fig. 139). Here the thallus is not only profusely branched but differs from the previously described types in having a continuous protoplasmic body containing numerous nuclei and chloroplasts. Septation occurs just before reproduction. In asexual reproduction, the whole contents of a terminal compartment which is cut off, forms multinucleate and multiciliated zoospore (synzoospore), which escape by rupturing the apex of the cell.

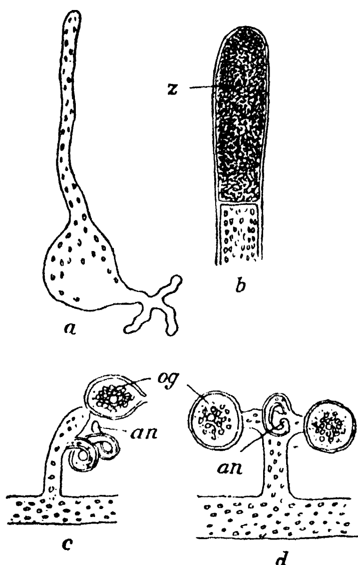


FIG. 139.—Vaucheria. *a*, a young plant with rhizoids; *b*, young sporangium; *c*, *d*, portion of filaments with antheridia (*an*) and oogonia (*og*). *z*=synzoospore.

In sexual reproduction, regular **Oogonia** and **Antheridia** are formed. These appear either as individual protuberances which grow out as lateral branches and become separated by forming partition walls or they are borne on the same branch. The **Spermatozoids** which are formed in the antheridia are very small and possess a single nucleus and two cilia. The oogonium which is spherical, develops a beak through which the spermatozoids enter. Only one spermatozoid fertilises the egg, which then becomes a resting spore. On germination the resting spore forms a filamentous alga once more.

Phæophyceæ or Brown algæ. These are mostly marine plants, and include many highly developed forms. We will examine one of the highly developed forms, viz., **Fucus** (Fig. 140). Asexual reproduction is unknown here. The thallus of Fucus is dichotomously branched and contains **air bladders** which help to keep it in position.

At the tips of the branches swollen structures are formed which bear special flask-shaped depressions termed **Conceptacles,** containing antheridia and oogonia.

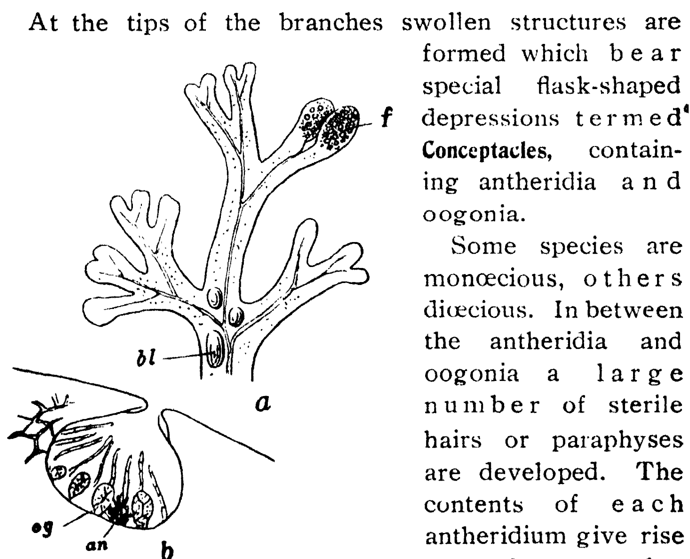


FIG. 140.—Fucus. *a*, A portion of thallus with bladders (*bl*) and conceptacles (*f*); *b*, section of a conceptacle showing oogonia (*og*) and antheridia.

Some species are monœcious, others diœcious. In between the antheridia and oogonia a large number of sterile hairs or paraphyses are developed. The contents of each antheridium give rise to a large number of bi-ciliate anthero-zoids. The oogonia are nearly spherical, and enclose eight spherical egg cells formed by the division of the mother oogonial cell. When the eggs are set free, such a large number of spermatozoids gather round them that they often set the egg in motion. Subsequently one sperm enters the egg and fertilises it, when it develops a cell wall and becomes attached to the substratum. It then develops into a new plant.

Rhodophyceæ or Floridæ are almost exclusively marine plants and they grow attached to the substratum. Their red colour is due to a red pigment **Phycoerythrin,** which completely masks the chlorophyll. Reproduction takes place both asexually and sexually. The various kinds of Agar-Agar are obtained from different members of this family.

Characeæ.—These plants occupy a peculiar position. They possess green chromatophores and are clearly

related to the Chlorophyceæ, though in some of their characters they resemble the Brown algæ.

In **Chara,** a representative of this family, note the main axis branches verticillately which again branches similarly (Fig. 141). The regular construction and habit of the plant is very characteristic. Asexual reproduction is unknown in this family. Sexual reproduction takes place by means of oogonia and antheridia. The plants are mostly monœcious. The male organ is really an antheridiophore, for it contains eight groups of antheridia inside it. The female organ is an oogonium containing a single egg cell. After fertilization the oospore becomes covered with a thick colourless cell wall. On germination the oospore forms a filamentous **Pro-embryo** which later forms the plant. In some plants the egg cells develop **Parthenogenetically,** i.e., without being fertilized by the sperms.

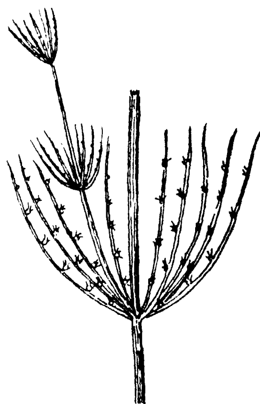


FIG. 141.—A portion of a Chara plant

FUNGI

This group differs from the algæ in the mode of nutrition. Since they possess no chlorophyll, the power of forming Carbohydrate is entirely lacking in fungi. They have to get their food from other organisms, either dead or living. When they get it from dead organisms, the fungi are called **saprophytic**; and when from the living, **parasitic.** Between these two forms, there are also fungi which can be both parasitic and saprophytic, or which change from one condition to the other as necessity arises.

Leading families of fungi are parallel in life history

with the leading types of algæ. It is possible that fungi whose life histories are parallel with algæ, may have been derived from them. In the primitive groups of fungi, the resemblances to the algæ are much greater than in the higher groups where they have undergone greater modification and specialization. The reproductive body in the fungus is a spore. The spores are extremely minute bodies. The vegetative body consists of septate or non-septate hyphæ (threads) known as the **Mycelium.**

The fungi are divided into three main groups, viz., **Phycomycetes** (e.g., Mucor or Rhizopus), **Ascomycetes** (e.g., Eurotium, Penicillium, Yeast), and **Basidiomycetes** (e.g., Agaricus).

Phycomycetes have a non-septate mycelium. In Asco- and Basidiomycetes the mycelia are septate. Ascomycetes differ from Basidiomycetes, in having spores, usually eight, borne inside a sac-like body (**Ascus**). In Basidiomycetes, the basidiospores, usually two or four, are borne exogenously.

The Common Bread Mould.—If a piece of bread is kept in a moist and warm place an abundant crop of Mucor is obtained. In this country, the mould is due mostly to a species of Rhizopus (**R. nigricans.** Fig. 142).

Note the fluffy tangle of mycelium formed on the bread. Examine a few hyphæ under the microscope and note that these threads are without any cross walls, branch freely, and run on all sides.

Observe that some of the hyphæ which arise above the substratum becomes swollen at the tips. These form the **Sporangia,** and are cut off by a transverse wall from the main hyphæ. This wall projects into the cavity of the sporangium and forms the **Columella.** At maturity the sporangial wall breaks and the spores are set free.

Mount some hyphæ with sporangia under the microscope and note the shape of the spores, sporangia

and columella. After the spores are liberated note that the sporangium wall remains as a collar to the base of

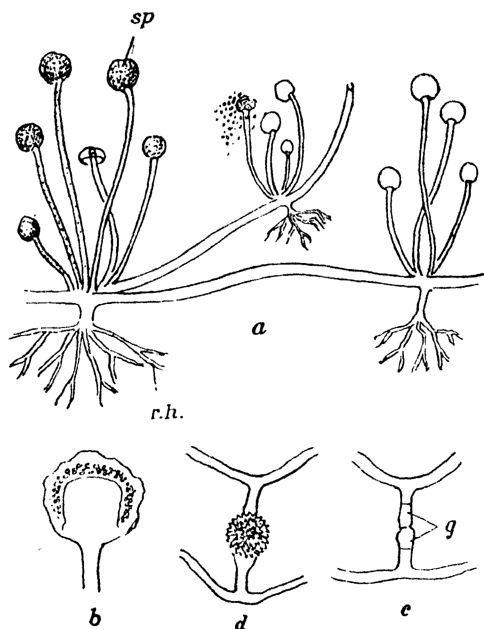


FIG. 142.—*a*, *Rhizopus nigricans*, sporangia (*sp*), spores and rhizoids (*rh*); *b*, sporangium; *c*, septation of the conjugating cells (*g*), *d*, zygospore formed.

the columella. The spores are very minute and light, and are easily carried about by currents of air. That is why they are present everywhere. The spores on finding a suitable substratum germinate at once, producing a mycelia with innumerable sporangia.

Besides the above mode of reproduction, reproduction by zygospore formation sometimes takes place. When this happens the hyphæ developed from two different spores approach, and their free ends meet together. The ends now become cut off by the formation of transverse walls and they become swollen. The

partition walls next dissolve, and the contents fuse and a zygospore is formed (Fig. 142,*d*). On germination the zygospore gives rise to an erect hypha which produces ordinary sporangiospores.

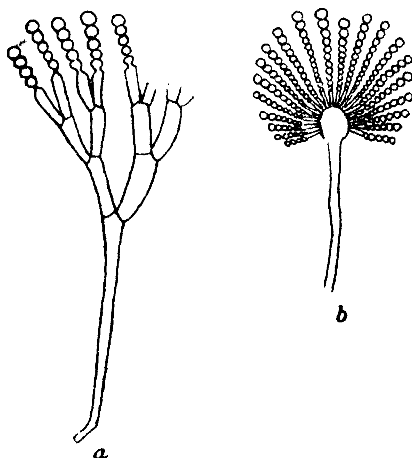


FIG. 143.—*a*, Penicillium; *b*, Aspergillus (*Eurotium*).

Penicillium and Aspergillus or **Eurotium** (Fig. 143) are two of the most common green mould fungi. They live saprophytically on organic substances. Penicillium is found commonly on decaying oranges and other fruits. The mycelium is septate, and in both cases asexual reproduction takes place by means of conidia abstricted in chains from a number of sterigmata, arranged radially on a swollen head.

Note that Penicillium differs from Aspergillus (Eurotium) in having branched conidiophores. Sexual reproduction takes place with the help of well-developed sexual organs. The ultimate result of sexual union is the formation of **ascospores**, i.e , spores formed inside an ascus or special sac. Ascospore formation is characteristic of all ascomycetes to which group Eurotium and Penicillium belong.

Saccharomyces or the Yeasts (Fig. 144) also belong to the ascomycetes, as ascospore formation takes place as a result of sexual union. These plants are economically very important as they have the power of fermenting sugar into alcohol. The Yeasts are unicellular plants. Mount a little yeast from the fermenting sugar solution in which some yeasts have been placed previously. Note that some of the cells are attached to smaller cells. The latter are budding off from the former. This mode of reproduction by budding is very characteristic of the yeasts.

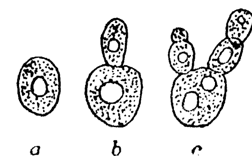


FIG. 144.—Yeasts (Saccharmyces). *a*, single cell; *b*, *c*, budding.

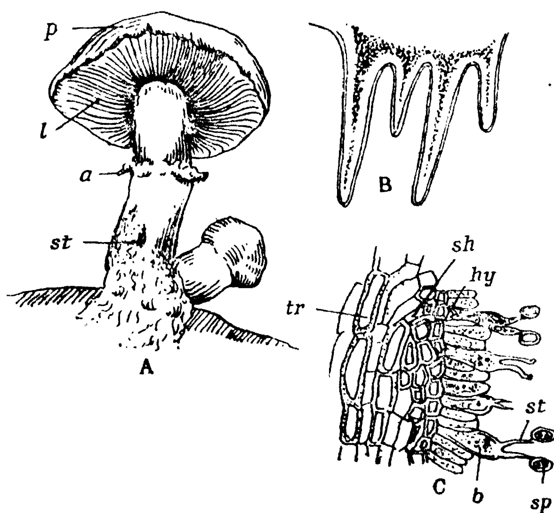


FIG. 145.—Mushroom. **A**. Fructification. *st*, stipe; *a*, annulus; *p*, pileus; *l*, lamellæ or gills. **B** Section of gill. **C**. Same more magnified. *tr*, trama, *sh*, sub-hymenial layer; *hy*, hymenial layer; *st*, sterigmata; *sp*, spore; *b*, basidia.

Let us now pass on to the common Agarics, popularly called the **Mushrooms**. They belong to the family

Basidiomycetes. These plants occur in places rich in decaying organic matters.

We will examine one of the commonest species, viz., **Agaricus (Psalliota) campestris.** What are sold in the market as Mushrooms are really the fructifications of the plants, and they bear the spores. Their vegetative body consists of a network of septate hyphæ which remain underground absorbing the food from the dead organic matters. At the time of fructification, a large number of hyphæ grow up together forming the umbrella-like structure.

Note that the cap-like portion or the **pileus** is borne on a stalk or **Stipe.** The pileus shows on its undersurface innumerable **Gills** or lamellæ. The gills bear club-shaped bodies or basidia with four spores each.

Now cut a transverse section of the gill and note

(1) the central **Trama** with straight septate hyphæ from which other septate hyphæ curve outwards ;

(2) on either side of the trama, note a layer of smaller cells, the **sub-hymenial** layer, outside which is the **hymenial** layer.

In the hymenial layer, note the sterile paraphyses and the basidia bearing the spores on **sterigmata.**

The spores on germination produce a mycelium from which again, the fructifications are formed.

LICHEN

Before concluding this chapter, we will mention the Lichens. These we have learnt are plants formed by the union of an alga and a fungus. The two live symbiotically. **Usnea** (Fig. 146), Parmelia, Cetraria, and Cora are common examples of lichens.

In the thallus, note that the algal cells become invested by the mycelium of the fungus. The algal cells remain green and hence can prepare their own

food material. The function of the fungus is probably that of absorption of water and salts. Reproduction usually takes place by means of **soredia**, when algal cells with fungus mycelium enclosing them, together form isolated knots which, rupturing the lichen thallus, are scattered in large numbers. These, when favourable conditions are present, produce new lichens. New lichens may also be formed by means of small separated bits of lichen.

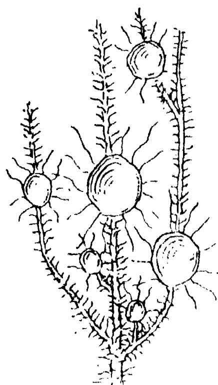


FIG. 146.—A lichen (*Usnea*).

CHAPTER XXXVIII

BRYOPHYTA

MOSSES AND LIVERWORTS

IN Bryophyta (Muscineæ), as also in the Pteridophyta, a regular alternation of generations is seen. The ordinary plant bears the sexual organ, viz., antheridia and archegonia, When the egg is fertilized, it gives rise to the **Sporogonium** (sporophytic plant). It remains permanently attached to the gametophyte. It consists of a **Foot,** a **Seta** (stalk), and a **Capsule.**

The Bryophytes comprise two classes, the Hepaticeæ (Liverworts) and Musci (Mosses). We will consider the Liverworts first and let us choose Marchantia and Riccia as examples of this group.

Marchantia.—Examine a plant of **M. polymorpha.** Note

(1) that the green plant has a creeping habit which goes on growing forward and branching dichotomously.

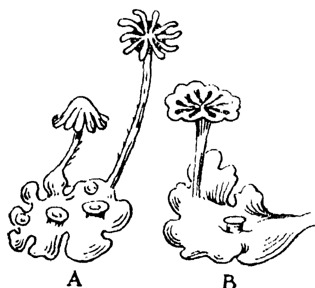


FIG. 147.—Marchantia. **A**. Female and **B**. male plant.

(2) The colourless **Rhizoids** by which the plant is firmly attached to the soil.

(3) The dorsiventrality of the thallus and the presence of ventral scales.

With the aid of a hand lens make out the **Air-Pores** on the upper surface of the thallus. These pores lead to the air chambers below. From the bottom of these air

chambers, a number of rows of cells containing chloroplasts arise, which perform the function of the assimilating tissue.

Next look for the cup-shaped outgrowths with toothed margins. These are situated on the upper surface and are termed **Cupules** or **Gemma-cups** for they contain stalked gemmæ. The gemmæ are bi-convex structures thick at the middle and gradually thinning at the edges. The two lateral notches seen contain the growing points.

Marchantia multiplies vegetatively by means of the gemmæ; sexually by means of sex organs borne on erect branches of the thallus, which consist of a stalk and an expanded upper portion (Fig. 147). The male branches terminate in lobed discs bearing antheridia on the upper surface on flask-shaped depressions, and the female branches end in long-rayed discs. Note that the archegonia are disposed in radial rows, between the rays surrounded by toothed involucre.

Now cut a longitudinal section of the archegonia and note the broader portion—**Ventor**—and the narrow portion —**Neck**—and the **Egg** inside the ventor. The egg after fertilization produces an embryo which develops into a stalked **Sporogonium.** The stalk or seta is attached by means of a **Foot,** and the capsule of the sporogonium when ripe contains spores and **Elators,** i.e., elongated spirally thickened cells. The elators assist in the dispersion of the spores, together with which they are discharged.

Riccia.—This is another Liverwort very common in the plains. It comes out in large numbers just after the rains. It is circular in shape and the plants are green at first, but later they become reddish. The plant has a very simple structure, the cells being more or less alike and containing chloroplasts. The sexual organs are borne on the same plant. The sporophyte consists of a sessile spherical sporangia. The spores are set free by

the disintegration of the sporogonial wall and the surrounding cells of the thallus.

Mosses.—(Fig. 148). These are all leafy plants occurring almost everywhere massed together in large patches. Note that the leaves are spirally arranged and that they consist of only one layer of cells. Note also the absence of stomata and that these plants have no true roots, but possess elongated hairs or **Rhizoids** which they send into the soil. Now cut longitudinal and transverse sections of the stem and make out the internal structures. Note

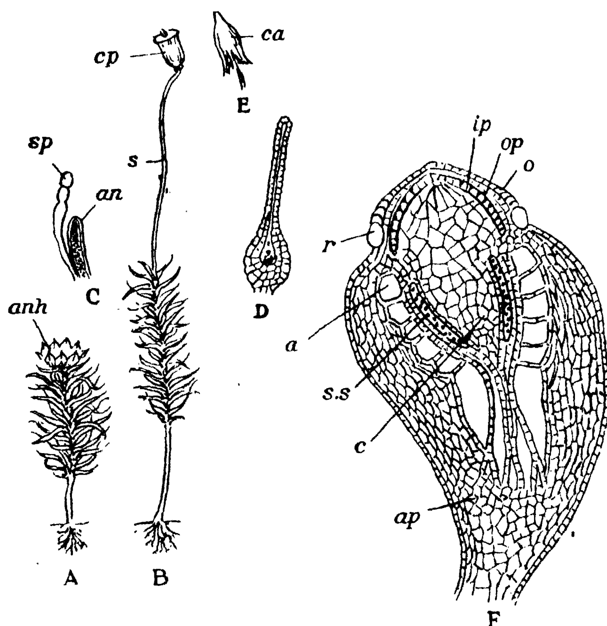


FIG. 148.—A—E. Polytrichum. *anh*, antheridial head ; *s*, seta ; *cp*, capsule ; *an*, antheridia ; *sp*, sterile hair ; *ca*, calyptra ; F. Section of a sporogonium of Funaria. *o*, operculum ; *op*, outer peristome ; *ip*, inner peristome ; *r*, ring ; *a*, airspace ; *c*, columella ; *ss*, spore sac ; *ap*, apophysis.

there is no differentiation of tissues, but the central thin-walled cells are more elongated than the outside cells.

The elongated cells are better fitted for conduction of water.

Many of the mosses can revive again after drying up when moisture is present. The ordinary moss plant is the gametophyte, bearing antheridia and archegonia. The fructification consists of a stalked sporangium, usually with a central axis containing very minute spores, which on falling on a suitable substratum germinates forming a thread-like branching filament **Protonema,** upon which leafy moss plants develop, bearing the sexual organs again. The archegonia are fertilized by spiral antherozoids liberated by the antheridia. The plants may be monœcious or diœcious. Between the sexual organs, a large number of multicellular hairs or paraphyses are present. As the sporogonium develops into a capsule, it carries with it the withered tip of the archegonium which is termed **Calyptra** (Fig. 148E). It is easily detached exposing the mouth of the sporogonium which is closed until maturity by a lid **(Operculum).** The operculum separates when ripe exposing a row of minute teeth, the **Peristome,** around the margin.

In a longitudinal section of the moss capsule (Fig. 148F) make out the axial **columella** consisting of sterile tissue, the **spore-sac** surrounding the columella, the **assimilating tissue,** the **water storing tissue,** and the **epidermis** towards the outside. Note also the teeth of the peristome, the **Operculum** and also possibly the section of the calyptra. At the margin of the operculum, note the narrow zone of epidermal cells, the Ring or **Annulus.**

The difference in the form of the capsule, peristome, operculum, and calyptra are important features for determining different genera.

CHAPTER XXXIX

PTERIDOPHYTA

FERNS, HORSETAILS, AND CLUB MOSSES

PTERIDOPHYTES include plants ranging from very small lowly plants to trees as much as 30 feet in height, as in the case of Tree Ferns. The ferns, Water ferns, Horse tails, and Club Mosses are included here. The sporophyte is much more complicated than that in the Bryophytes. It has true roots, stems and leaves with highly differentiated internal structure.

Ferns are very commonly cultivated all over the country. They are also found growing wild. Aspidium (Fig. 149A), Pteris, Adiantum (Fig. 149B), or Goniopteris may be examined.

Note that they have underground stems (rhizomes) and much developed leaves that are coiled circinately before expansion ; observe the scales at the bases of the stalks. Roots are given off from all sides of the stem.

Next make out the internal anatomy of the stem. Cut both longitudinal and transverse sections of the stem, and make out how the vascular system forms a hollow cylinder of a network of strands, in the common ferns. Each strand consists of thick walled xylem vessels consisting of tracheids (and not vessels resulting from fusions of cells) surrounded by thin walled phloëm enclosed within the Pericycle, which in turn is surrounded by the endodermis. Mark the absence of cambium. The rest of the stem consists of parenchymatous and sclerenchymatous tissues. The internal structure of the leaflet is very similar to that of the bifacial leaves in the phanerogams.

Note that the fructifications on the undersurface of the frond consist of usually densely clustered capsules

(sporangia) containing microscopic spores. The globose clusters of sporangia become brown when ripe and these are termed **Sori** (Fig. 149D). Note that the sori are at first protected by a peltate membrane, the **Indusium** which later

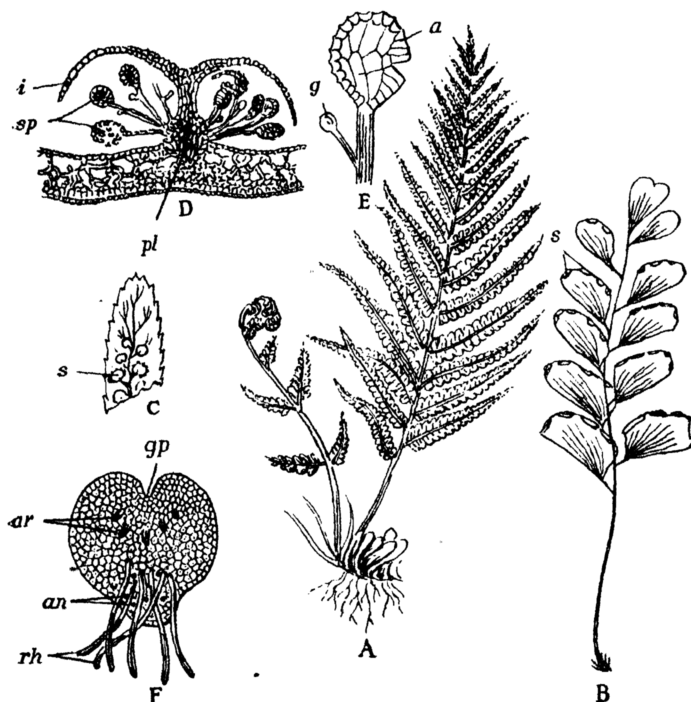


FIG. 149.—A. Aspidium filix-mas. B. Adiantum. C. Pinna with young sori (*s*). D. Sorus in vertical section showing sporangia (*sp*) arising from *pl*, the base of the indusium (*i*), E. Single sporangium showing annulus (*a*) and a gland hair (*g*). F. Prothallus. *gp*. growing point; *ar*. archegonia; *an*, antheridia; *rh*, rhizoids.

on disintegrates, exposing the minute stalked sporangia. Each sporangium contains an indefinite number of spores, which are liberated by dehiscence with the help of the Ring or **annulus** which is specially adapted for the purpose.

Next collect some spores and germinate on a moist blotting-paper, which should be kept covered in a warm place. Note that the spores on germination develop into small leafy expansions, the **Prothalli** (Sing. Prothallium, Fig. 149F), which bear the sexual organs. Observe the growing point of the prothallus lies in the anterior notch.

In the prothalli, observe the simple unseptate rhizoids on the ventral surface, and near the notch, notice the projecting necks of the archegonia. Further down, the spherical projecting antheridia may be made out with a hand lens. The large egg-cell of the archegonium is fertilized by the active sperm liberated by the antheridia. When fertilized, the zygote develops into an ordinary sporophytic plant. Thus a clear alternation of generations is seen in these plants.

Sometimes the sporophyte may develop from the prothallus vegetatively by budding, when sex organs remain abortive. This case is known as **Apogamy.** An opposite case, **Apospory,** happens when new plants are developed from leaf buds, without the formation of the spores.

Water Ferns (Hydropterideæ). Only a few genera are included here, and these are more or less aquatic in habit. The spores are heterosporous, unlike those of the ordinary ferns we have studied which were all homosporous. In Water Ferns, the **Micro** (Male) and the **Macro** (Female) sporangia are developed within special covered receptacles called **Sporocarps.** We will here consider Marsillia and Salvinia, representatives respectively from the two important families Marsiliaceæ and Salviniaceæ.

Marsillia (Fig. 150). These plants are very common in moist places by the sides of ditches and water pools.

Observe the horizontal slender creeping stem with branched axis bearing leaves above and roots below.

Each leaf has a long erect petiole bearing four cuneate leaflets, peltately. The leaves as in all ferns are circinately folded when young.

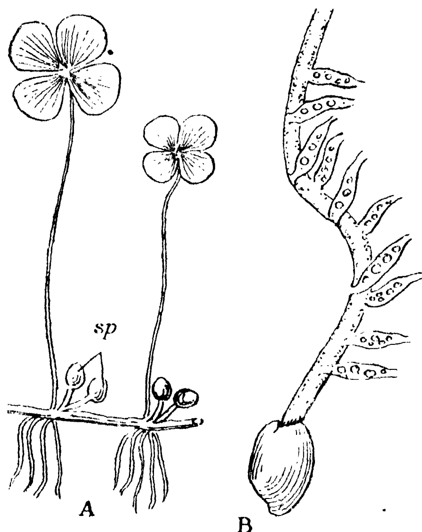


FIG. 150.—*Marsillia quadrifolia*. **A**. A plant with sporocarps (*sp*). **B**. Sporocarp burst open, showing sori on gelatinous stalk.

The stalked oval sporocarps are usually in pairs above the base of the leaf stalks. The sporocarps in Marsillia are very hard bodies, which split when ripe and a mucilagenous ring comes out bearing a large number of sori consisting of both **Megasporangia** and **Microsporangia** (Fig. 150,B). The microspore germinating forms the male gametophyte (male prothallium) which remains inside the spore, and forms a single antheridium. The antherozoids formed are spirally coiled bodies with cilia on the lower end. The female gametophyte is also very small and remains within the megaspore. The egg-cell when fertilized develops into a new plant.

The Salviniaceæ include only two genera, **Salvinia** and **Azolla.** Both are free floating forms. We will study Salvinia only (Fig. 151).

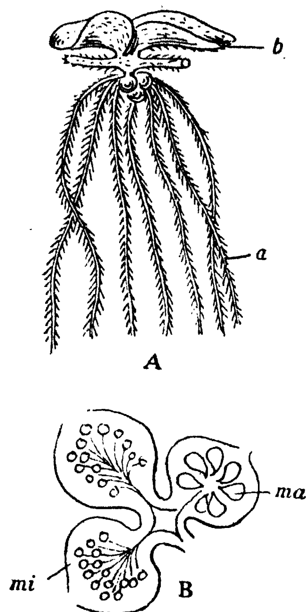


FIG. 151.—Salvinia. A. A plant seen from the side. *b*, floating leaves: *a*, submerged leaf. B. Micro (*mi*) and Mega (*ma*) sporocarps.

Note that

(1) the stem at each node bears three leaves, two upper ordinary floating foliage leaves and a third submerged segmented root-like leaf.

(2) Absence of roots. The function of the roots is taken up by the segmented submerged leaves.

(3) Small spherical sporocarps borne on the filamentous segments of the submerged leaves.

Next examine a number of sporocarps and make out that they either contain numerous microsporangia or a few macrosporangia. The sporangia are without any annulus as in Marsillia. The microspores develop within the microsporangia. The male prothallus develops a number of antheridia each of which bears four sperm cells. In the macrosporangia, only one macrospore develops forming a female prothallus. Rupturing the spore wall and the wall of the sporangia the green prothallus comes out. It has only three archegonia of which only the first fertilized one develops into an embryo which forms a new plant again.

CHAPTER XL

THE HORSETAILS (EQUISITINEÆ) AND THE CLUB MOSSES (LYCOPODINEÆ)

THE **Equisitineæ** include only one genus Equisetum (Fig. 152). The plant has an underground branching stem (rhizome) from which ærial shoots come out either

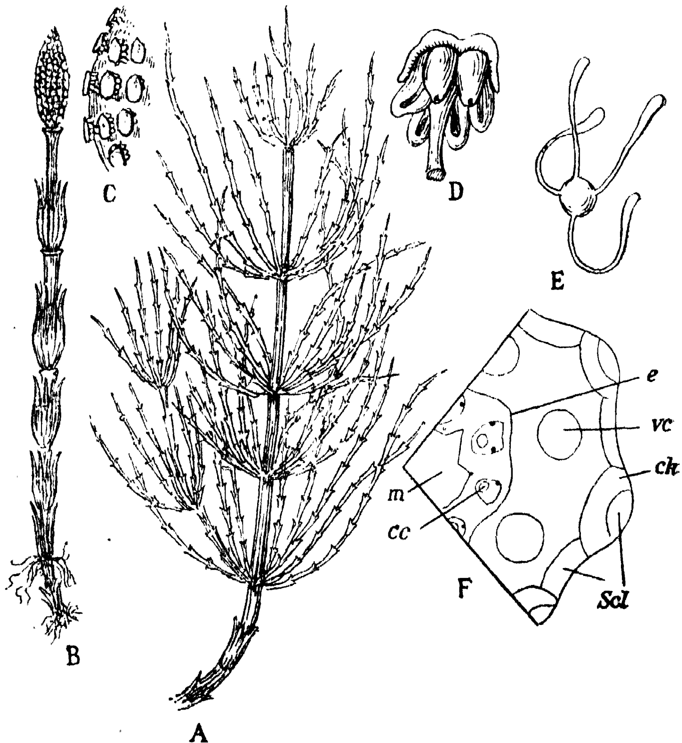


Fig. 152.—Equisetum. **A**, Sterile shoot. **B**. Fertile shoot, **C**. Portion of a cone magnified. **D**. Sporophyll bearing sporangia, **E**. Spores with elators. **F**. Part of a section of a stem, *scl*, sclerenchymatous strands; *ch*, chlorophyll bearing tissue; *e*, endodermis; *m*, medullary cavity-lyseginic; *vc*, vallecular cavity; *cc*, carinal cavity.

singly or in tufts. The ærial portions are ribbed, hollow and jointed, with or without whorled jointed branches.

Note that at each node a whorl of scale leaves, toothed above but united below, forms a sheath enveloping the base of the internode. The lateral branches when given off pierce the narrow sheaths to grow upwards.

Observe the green colour of the shoot which has taken up the function of assimilation.

Next cut a section of the shoot at the node and make out the internal structures (Fig. 152F). Note that (1), the vascular bundles are **Collateral** (xylem towards the centre and phloëm outside) and not concentric as in the ferns, (2) the green colour due to the chlorophyll tissue in the cortex, (3) the hollow pith due to disintegration of cells in the centre, (4) the air-spaces in place of the protoxylem elements termed **Carinal** cavities, and (5) the large spaces in the cortical regions called **Vallecular** cavities. Note also the presence of the endodermis on both sides of the bundles and also the thickened sclerenchyma at the ridges.

The structure of the rhizome is similar to that of the shoot. In the root the arrangement is usually triarch. The leaves are very simple and do not show much differentiation of the tissues.

Let us now examine a fertile shoot of Equisetum. (Fig. 152B,C). Note that the fructification consists of a terminal spike of numerous closely packed peltate scales, bearing sporangia of one kind around their margins. The lowest whorl of the spike or cone is sterile and forms a sort of collar. The sporangia split longitudinally discharging a large number of green spores The outer coats of the spores split into elastic attached filaments, the **Elators.** By means of the hygroscopic movement of the elators, a large number of spores are hooked together thus ensuring close proximity of the prothalli which are generally unisexual.

Equisetum debile, which is found in large numbers all over the Punjab, and also on the banks of the Padma in

Bengal, and in other parts of India as well, has an inflated cushion-shaped prothallium which is bi-sexual. The prothallium bears archegonia first and antheridia later. Prothalli can be grown in the laboratory and often young plants may be seen coming out of the prothalli.

Club Mosses—include the two most important plants, the Lycopodium and the Selaginella. These are low trailing, wiry herbs, with small leaves. The dichotomous branching of the stem and the root, and the simple forms of the leaves are very characteristic features.

Lycopodium.—(Fig. 153). Here the leaves are usually subulate and imbricated around the stem. The creeping stem branches dichotomously and gives rise to erect lateral branches. From the under surface, dichotomously branched roots come out. Observe the pair of cone-like structures at the ends of forked erect shoots. Note that they consist of closely aggregated sporophyll which are broader and pointed at the tips than the sterile leaves. See how the sporangia are situated near the base on the upper surface of the sporophylls. The sporangium contains numerous minute spores which come out by the transverse splitting of the sporangium. The spores are all alike and the prothallia developed from them are all monœcious. The embryo when formed remains during its development enclosed in the

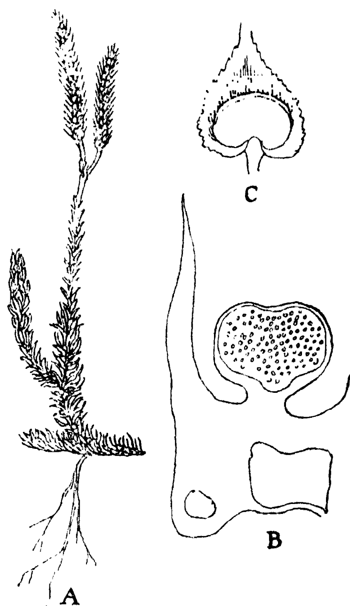


Fig. 153.—Lycopodium. **A**. Plant bearing cones. **B**. Section of a sporangia and C. Sporangia on a sporophyll.

prothallus and has a spherical foot which acts as an absorbing organ. The young shoot is formed beneath the foot and from the base of the shoot, the first root grows out.

In a prepared longitudinal section of the prothallium, note the above structures and also the **Suspensor** situated between the shoot and the foot, which serves both as an absorbing and nourishing organ to the embryo.

In India, the Lycopods are mostly confined to the humid hilly regions.

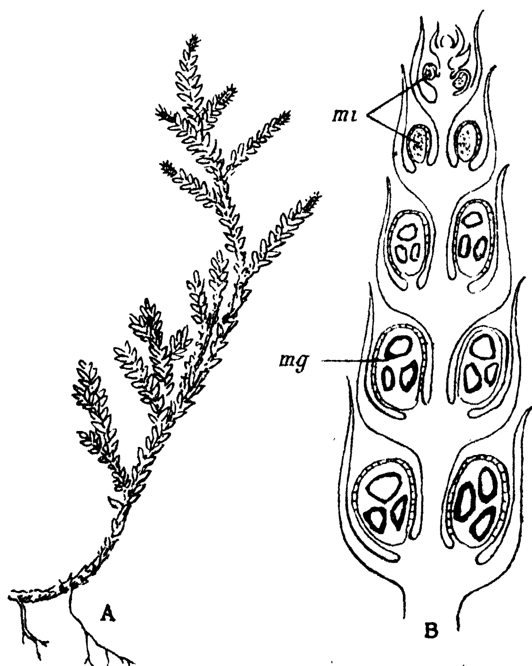


Fig. 154.—Selaginella. A. A plant bearing cones. B. Section of a cone showing micro (*mi*) and mega (*mg*) sporangia.

Selaginella.—(Fig. 154). These are mostly tropical plants. As a rule they are profusely forked and mostly

creeping plants. The leaves are of two kinds; the larger usually obliquely oblong are distichously arranged in the plane of ramification and the smaller, stipule-like, are appressed and intermediate. Presence of **Rhizophores** is very characteristic of the Selaginellas. These are cylindrical, leafless, shoot-like structures, and arise exogenously at the bi-furcations of the stems. The rhizophores give off roots when they come in contact with the soil.

Now cut a transverse section of the stem and note the single central **Stele** (in many polystelic) surrounded by a trabecular endodermis, inside the green cortex, with the outermost layer of epidermis. The stele consists of a central xylem surrounded by phloëm. In the rhizophore and in the root, the phloëm surrounds the xylem in horse-shoe fashion, the portion of the protoxylem remaining free.

Now examine a spike of Selaginella. The cones or flowers are terminal. They are simple or branched and radially symmetrical. Cut a radial longitudinal section of the cone (Fig. 154B). Note that the sporangium springs from the stem above the leaf-axil, and that the same spike bears both micro and megasporangia. The microsporangia bear numerous small spores and the megasporangia only four large spores. The microspores begin their development while still enclosed within the sporangium. In some species, the microspores also begin their development similarly. The archegonia are not however formed, till the spores have been discharged from the sporangium. After fertilization, the egg cell directly develops, forming the embryo.

PART VI.

ECOLOGY, EVOLUTION, HEREDITY

CHAPTER XLI

ECOLOGY

Ecology.—We have so far studied the individual plants. Now we will study the forms of plants in their natural homes or their **ecology.** The word ecology comes from the Greek words **Oikos**—a house, and **Logos**—a study, meaning the study of their household affairs.

Plants are mostly gregarious beings. This is because they are fixed to the soil and propagate themselves largely in social masses either from broad cast seeds or spores or vegetatively by means of rhizomes, runners, etc. In this way they produce '**vegetation**', as plant growth in mass is conveniently called, and this is naturally found to fall into '**plant communities.**' Division of plants and plant communities depend upon '**habitat factors.**' Habitat includes all the factors of environment which affect a plant or a plant community. According to Warming, the ecological classes are:—

1. **Hydrophytes** or aquatic plants. In it are included the vegetation as found in a watery or wet substratum with at least 80 per cent of water.
2. **Xerophytes,** include those plants which live in very dry places where the soil has less than 10 per cent of water.
3. **Halophytes,** include those plants which live in a saline soil.
4. **Mesophytes,** include such plants as live in localities which are neither too wet nor too dry, nor specially salty.

The above classes are however incapable of exact definitions and are used in a very limited sense. To the above ecological classes may be added a fifth one, viz.

5. **Epiphytes** or plants which live on other plants, or at least a part of their lives on other plants.

We will consider now the above classes in more detail.

Hydrophytes.—The difference between an aquatic plant and a land plant is obvious. Take a Vallisnaria or a Hydrilla out of the water and note that it is incapable of remaining erect. This flaccidity is due to want of xylem and other tissues, so characteristic of land plants.

Note the development of large air-spaces in the tissues of the water plants. The air spaces lessen the specific gravity, and floating the plants support their weight. The air spaces also help in the process of respiration. As the water plants absorb the food material in solution throughout their bodies the elaborate absorbing system of the land plants becomes unnecessary and the roots and root-hairs when present, function as organs of attachment only.

Note that the epidermis in submerged plants develops no cutin or stomata and as the light inside the water is diffused, no differentiation into spongy and pallisade parenchyma takes place.

Water plants may be either free swimming or attached to the substratum. In still water, the plants develop large leaves, but in running water, the leaves are ribbon-shaped and dissected. Plants like Nymphæa whose leaves always float on the surface of water, have large thick leaves with plenty of cuticle or wax and stomata on the upper surface.

Marsh plants which remain only partly submerged show heterophylly, i.e., leaves that are submerged differ very much from the ærial leaves. The possession of ærial leaves by the marsh plants, helps them to grow in stagnant pools were the amount of oxygen is very low.

Xerophytes.—These are plants growing in very dry regions. With scarcity of water, the vegetation suffers very much and the plants become stunted. When plants grow in places with a prolonged dry climate, they get modified in various directions and although of widely different families, they all become remarkably similar and present definite growth forms.

The modifications in the xerophytes are made with the one purpose of preventing the loss of water by excessive transpiration.

The different growth forms represented may be grouped as follows, viz.—

(1) those with long roots and small thickened leaves with only a few sunken stomata (e.g., **Indigofera trita, Desmodium bi-articulatum**, etc.) ;

(2) those with fibrous roots and special water absorbing parenchyma, fleshy stem and no leaves. If leaves are present, these drop off early (e.g., Prickly Pear) ;

(3) those in which the leaves become fleshy and thick and act as a store-house for water (e.g., Agaves and Aloes).

Halophytes.—These are plants of the saline soil and have to take the water very slowly and sparingly ; hence they present a great similarity to the xerophytic adaptations.

While ordinary xerophytes as in a desert, suffer from **physical drought,** the halophytes are subjected to **physiological drought.**

The majority of the halophytic plants are leaf-succulents (e.g., Chenopodiaceæ), but a few are stem succulents (e.g., Asclepiadaceæ). Some halophytes if planted out in non-saline soil lose their succulence. Of the halophytes, living near the sea-shore, may be mentioned Rhizophora, Sonneratia, and Heritiera which form the '**mangrove forest**'. These plants develop **Pneumatophores** or erect breathing roots and are **Viviparous**

i.e., their seeds germinate inside the fruit when still attached to the plant.

Mesophytes.—These include the average land plants thriving in a soil of moderate humidity and avoiding marshy and saline soil.

The leaves are varied in form and adapted for rapid transpiration. No special water storage tissue is necessary and is not developed. The special feature is the development of a strong supporting tissue system.

Epiphytes.—These plants attach themselves to other plants but do not abstract anything from the supporting plants.

The Orchids, Aroids, and the Figs are common epiphytes in this country. The first two plants possess aerial roots for the absorption of water. The aerial roots are whitish, due to a sheath of several empty layers of cells which ordinarily contain air. The sheath is called **Velamen.** These plants have to depend on mists or rains for their water-supply which is very scarce and hence develop xerophytic adaptation.

The Ficuses begin their lives as epiphytes but soon send their roots down to the soil and become established there, the supporting plants being usually killed.

Before concluding this chapter we will mention the factors influencing the distribution of plants. There are principally nine factors, viz.—

1. Temperature. Different species of plants require different degrees of temperature for their healthy growth. The vegetation of the globe is divided according to the different degrees of mean annual temperature into **Zones,** viz., (*a*) **Tropical,** (*b*) **Sub-Tropical,** (*c*) **Temperate** and (*d*) **Frigid.**
2. Water. This is indispensible for all plants though in varying degrees ; water acts as an agent for the distribution of seeds across the sea (e.g. Cocoanuts).

3. Soil. Also called the **Edaphic** factor. Rocky soil favours the growth of lichens, shallow soil the growth of grasses, and deep soil the growth of herbs and shrubs.
4. Light. In high elevations light is more intense than in the lower lands. It has influence on the distribution of plants. Grasses cannot grow in a dense forest as they cannot get the requisite amount of light in the undergrowth. Shade loving plants are found only in the shades.
5. Air. Winds carry pollen grains of grasses and conifers, and distribute winged seeds. It also regulates humidity.
6. Existence of other plants. Some plants are able to grow in the open, while others grow in the shade and require to be sheltered by other plants.
7. Action of Man. Man brings plants from distant localities and introduces them to new localities, which otherwise would have been inaccessible and unknown to the plants. These plants adapt themselves to their new localities and manage to live. Man may introduce new plants quite unknown to himself. Many small fruits, seeds, etc., stick to the clothes and may be introduced to new localities. Man again destroys enormous areas by clearing for the purpose of cultivation.
8. Existence of other animals. Birds and animals devour fruits of particular species of plants and pass out the stone or seed and thus distribute the species from one placc to another.
9. Fire. By occasional breaking out of fires, vast tracts of forest vegetation are demolished and succeeded by other humbler types of vegetation.

CHAPTER XLII

EVOLUTION AND HEREDITY

EVOLUTION means gradual change. It implies that things were not in the beginning as we find them now. The plants have changed from relatively simple organisms to those more complex. Most of the steps of evolution have been progressive, i.e., towards higher organization, greater perfection of parts, increased efficiency of function, e.g., from algæ to angiosperms. Sometimes again, evolution instead of being progressive has been retrogressive, i.e., towards simpler organizations, less perfection of parts, decreased efficiency of function, as from green algæ to phycomycetes, from independence to parasitism as in Dodder, or to saprophytism as in Bread Mould. The above developmental changes in the living beings constitute the **Organic Evolution.** Such changes are manifested in the development of a spore or egg to a mature individual **(Ontogeny),** or in the development of a group of related forms **(Phyllogeny,** or the development of the race).

One of the main problems of Botany is to record in order the evolutionary steps that have culminated in the present condition of the plant world. All biologists agree that evolution depends ultimately on **Variation** and **Heredity.** Darwin entitled his great book *The Origin of Species*, because the essential step, so to speak, in evolution consists in the transition of one species to another. If a species A, is to give rise to a species B, then in the first place some individuals of A, must vary in the direction of B, and then the variation must be inherited, or otherwise no permanent change can take place. We see then that our ideas of heredity and

variation become naturally linked with the theory of evolution, and thus the history of two subjects largely coincides.

An important landmark in the theories of evolution was the work of Lamarck in 1809. According to this theory, '**acquired variations**' are being continually produced and perfected by every organism during its life time, and that they are, at least partially, transmitted to its offspring.

Darwin (1859) attached great importance to continuous variations, and according to him, if variation useful to any organic being should occur, then individuals thus characterized will have the best chance of being preserved in the '**struggle for existence**'; and from the principle of inheritance, these will tend to produce offsprings similarly characterized. This principle of preservation or '**survival of the fittest**', Darwin called '**Natural Selection**'; and it leads to the improvement of each creature in relation to its organic and inorganic conditions of life and consequently may be regarded as an advance in organization.

Hugo de Vries was the first to point out clearly the facts about variation after actual experiments. He studied in detail the nature of the discontinuous variations by means of experimental methods, and in the year 1901, brought forward his new theory of **Discontinuous Variation** which he called the '**Mutation**' theory. Mutations appear suddenly and they are very striking in character and breed true.

The mutation theory of de Vries has not been intended to supplant the theory of **Natural selections** but to demonstrate that the material upon which selection acts in the formation of new species are mutations and mutations only, and never fluctuating or individual variations.

Mutation offers a new method by which evolutionary changes may take place within a much shorter

time than was demanded by the theory of continuous variations. The mutation theory clearly shows that the absence of 'connecting links' between species is no argument against evolution but is on the contrary what we might expect to find.

It may be mentioned here that Kamerer's experimental results in recent years, tend to support the theory of 'continuous variation' and it has raised great controversy again.

Long before de Vries, Gregor Mendel in 1866 studied the laws governing the formation and development of hybrids with special reference to the laws according to which various characters of parents appear in their offspring. He found that when he took two strains of peas possessing a pair of contrasted characters, e.g., one tall and the other dwarf, and artificially crossed them with each other in any way, the result was that the hybrids were always talls. For this reason, Mendel termed tallness the **Dominant**, and dwarfness the **Recessive** character.

Sowing the seeds of these hybrid talls the next year, gave rise to a mixed generation, consisting of talls and dwarfs and no intermediates. By raising a considerable number of plants, Mendel was able to establish the fact that the number of talls which occurred in this generation was exactly three times as great as the number of dwarfs.

The seeds from the second hybrid, or filial generation, were then raised and the seeds from each individual plant were harvested and sown separately in the following year. The seeds from the dwarf recessives bred true for every dwarf tested. It was however different with the talls. Although indistinguishable in appearance some of them bred true while others behaved like the original tall hybrids, giving a generation consisting of talls and dwarfs, in the proportion of three of the former to one of the latter. Counting showed that the number of

talls which gave dwarfs, was double that of the talls which bred true.

Thus if we denote a dwarf plant by D, and a true breeding tall as T, and a tall which gives both talls and dwarfs as T (D), the result may be summarized as follows:—

```
                T × D,        ...      ...  Parents.
                  |
                T (D),        ...      ...  F1, generation.
                  |
 _________________|__________________
T      T (D)        T (D)     D,       ...  F2,    do.
|        |                    |
T   T, T(D), T(D), D.         D,       ...  F3,    do.
|                             |
T                             D,       ...  F4,    do.
```

Mendel experimented with other pairs of contrasted characters and found that in every instance they followed the same scheme.

According to him a gamete could carry 'one and only one of any alternative pair of character.' Thus a gamete could carry tallness or dwarfness but not both, and this conception of the '**purity of gametes**' is the most essential part of Mendel's theory.

Mendel's discovery is of great practical value. His laws help breeders to know what the effects of the cross would be and as the contrasting characters behave independently, useful characters found in different plants may be combined in one.

APPENDIX

APPARATUS, ETC., REQUIRED

THE Apparatus and Reagents required for this practical course are, with the exception of the compound microscope, inexpensive, and much of the apparatus, especially that used in physiological experiments, can be advantageously made by the students themselves.

It is quite a mistake to imagine that scientific work of value can only be accomplished with the aid of elaborate and expensive instruments. Much of the very best work has been done by means of home-made apparatus costing but a few annas to arrange.

The following list includes the requisite apparatus and reagents; those in brackets are useful, but can be dispensed with.

1. Two or more needles mounted in wooden handles.

2. A **small** scalpel.

3. A knife.

4. A pair of forceps. Steel ones with the ends roughened are the best. Brass forceps are of very little use.

(5. A pair of small scissors.)

6. A piece of sheet cork, about 5 × 3 inches, weighted with lead so as to make it sink in water.

(7. A dish to take the last-named cork.)

8. A razor, slightly hollow ground, and a strop. It is best to get a really **good** razor.

9. A hand-lens, with triplet combination. (Cost about 3*s*. 6*d*.) This can easily be converted into a very useful dissecting microscope by mounting it in the way shown in the annexed figure (Fig. 155). The bottle (B) contains shot in order to render it stable; through the cork passes a stout wire or knitting-pin, W. On this a cork (C) slides

stiffly. Through the latter a second wire (W_1) is passed, also sliding stiffly. The end is turned up at right angles, and passes through the holes made in the holder of the lens. In this holder is another cork (C_1) through which the wire passes, and which serves to fix the lens firmly on the wire.

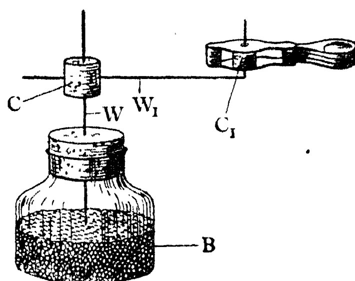


Fig. 155.

Thus you have a lens, mounted on a firm support, capable of being turned in any direction, and nearly as serviceable as the elaborate dissecting microscopes for which £2 are often charged.

10. A compound microscope, with 1 inch and $\frac{1}{6}$ inch objectives, and two oculars. (Cost about £6 10*s*.)

11. Glass slips and cover-glasses for mounting objects.

12. Glass and indiarubber tubing.

13. Test-tubes of various sizes, and a stand (which can easily be made at home.

14. Bottles of various sizes, including pickle bottles.

(15. A set of six stoppered bottles with glass dipping rods, for reagents. Those which are provided with hollow glass caps instead of stoppers are the best.)

16. The following reagents : **Alcohol** (which should mix with water without becoming milky) ; **Caustic Potash** (only a little should be made into solution at a time, as the stoppers of bottles containing it are apt to become fixed); **Sulphuric** and **Acetic Acids**; **Glycerine, Iodine** (this should be dissolved in water to which a crystal of potassium iodide has been added) : **Hæmatoxylin Solution**; **Methylene Blue** (solid), **Vaseline, Solid Paraffin, Calcium Nitrate, Sodium Nitrate, Potassium Phosphate, Magnesium Sulphate.**

INDEX